Flax: Sustainability Is the New Luxury

Joan Farrer and Carolyn Watt

Abstract 'Flax: increasing its value for society' was the challenge posed by cross-border researchers funded by the European Union INTERREG IV A France (Channel)—England call, as the ancient flax fiber had seen a dramatic decline in consumer appeal and market share. The resulting collaboration, ProjectFlax, delivered new innovations where novel applications in sustainable materials for human and environmental wellbeing produced premium products from an unexpected plant source. Could value in future be defined and measured not just by the aesthetics of the artefact, but by assessing the true value of materials using a holistic narrative in relation to process, the philosophy and sustainability of the application? This assessment is, we argue, *new luxury*. The purpose of this chapter is to show that flax was an unexpected source of innovation for societal advantage, appealing to consumers who desired a deeper material meaning and product differentiation—characteristics afforded by traditional expensive luxury brands. The collaboration between design, science, technology, engineering, mathematics and business (D-STEM-B) combined discipline methodologies, which resulted in new thinking and problem solving. Case study, desk-based, laboratory, practice-led, field study, quantitative, qualitative, narrative and observational methods were explored by 20 national and international, commercial and institutional flax researchers. The findings included improved agricultural and industrial production methods, composites, foodstuffs, biodegradable packaging, bio materials, fashion and interior product prototypes. The research has contributed to a knowledge transfer toolbox between D-STEM-B partners and advanced transdisciplinary working methods, which resulted in further successful funding applications and new market opportunities for flax.

Keywords Flax · Sustainable materials · Luxury · Transdisciplinary · Design · Science · Business · Wellbeing · Agriculture

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M.A. Gardetti and S.S. Muthu (eds.), *Handbook of Sustainable Luxury Textiles and Fashion*, Environmental Footprints and Eco-design of Products and Processes,
DOI 10.1007/978-981-287-633-1_2

1 Introduction

Flax is the common name for the fibres of *Linum usitatissimum*, part of the linen family, and is one of the oldest cultivated crops used in textiles and foodstuffs. Throughout history, the various qualities of flax have been valued for a variety of different purposes. As a material, it ranks highly in the fabric hierarchy because its fibres could be made by hand into strong, decorative, gossamer-like woven linens and lace, were superior to other fibres and were enjoyed by the privileged. This was, without doubt, an *old luxury* fibre. The discovery in a cave in Georgia of dyed flax fibers has been dated to 34,000 BCE, suggesting that ancient peoples spun wild flax fibers to create linen-like fabrics. Flax bandages have also been discovered wrapped around mummified corpses in Egyptian tombs and in ancient Egyptian medical applications [7: 27], and tomb illustrations depict in detail the cultivation, production and use of linen cloth. Such high quality cloth could be achieved prior to the modern industrial age due to the long fine fibres, which can reach up to one metre in length, found in the core of the flax stalk. These strong fibres are laid bare when the outer pithy casing has been removed in what is known as the retting process,[1] whereby the rows of cut stalks are left to lie in the field where they are grown, exposed to wind, rain and sun in the natural environment for six weeks, and turned once or twice (these more sustainable processes with minimal use of chemicals, result in better environmental management of the land and improved working conditions for processing and manufacturing). Flax grows primarily in damp temperate climates in parts of the world that share particular latitudes; however, the resulting high quality linen is made from flax grown principally in European countries and regions of China. Flax is able to grow on the majority of soils and, in contrast to many other fibres such as cotton, natural production of flax does not require pesticides, artificial irrigation or fertilisers, resulting in a truly organic fibre.

Fine flax fibres can be easily spun into extremely fine thread by using simple hand spinning devices such as a distaff and spindle. The thread could then be dyed and hand braided into fishnets and ropes, or woven into fabric strips on primitive looms before being sewn together to make clothing and furnishings. The plant has also been cultivated for its many by-products, ranging from foodstuffs and medicines to soap, paper and dyes. The seeds of the flax plant, called flaxseed, are used to make edible oil known as linseed oil. 'Flaxseed has a unique fatty acid profile. It is high in polyunsaturated fatty acids and low in saturated fatty acids' (Mridula et al. 2013: 950). Today, rich omega fatty acids are known to be beneficial to health, and it is thought that regular inclusion of flaxseed in a nutritionally-balanced diet reduces levels of blood cholesterol and, consequently, the risk

[1]Retting is the process employing the action of micro-organisms and moisture on plants to rot away much of the cellular tissues and pectins surrounding the bast-fibre bundles, facilitating the separation of the fibre from the stem.

of coronary artery disease. Flax has a long history as a source of food, health and wellbeing. The healing properties of flax have been known from ancient times, evidenced when Hippocrates claimed that flax seeds can be used for relief of abdominal pains, and the oil from flax seeds has been used in food for thousands of years [5: 2]. Contemporary research attention is beginning to focus upon food production, vegetable waste and bio-resources.

The fibre's multiple uses, including luxury textile manufacture, achieved status and popularity, continuing throughout the Industrial Revolution, but began to lose market share and popularity as the fibre was replaced by oil-based fibres such as polyester, with a similar handle and strength, but which were crease resistant and could be mass produced cheaply. In the 1960s, flax did not develop a brand identity (unlike other fibres such as cotton and wool, through the auspices of Cotton Incorporated PLC and the International Wool Secretariat, respectively). Coupled with the burgeoning global trade in easy care man-made fibres, linen's luxury market niche began to lose its place in the luxury hierarchy (Miller and Mills 2012).

Flax, once known as the luxurious 'gold of the Nile', has been rediscovered in the last decade in design, science and engineering communities due to its positive environmental credentials. The chief component of flax, cellulose, is 'one of the oldest, most abundant natural polymers on earth [sic]' [14: 207]. Alongside lignin and hemicellulos, this key component of the flax fiber increases its value in the materials hierarchy because of the way it can be produced and the research and development opportunities attractive to new markets. In addition, these fibres are now much sought after as they are recyclable, biodegradable and are 'carbon positive', which means the plants absorb more carbon dioxide in the growth phase than they release during processing; yet flax fibre now accounts for only 0.7 % of the world's fibre production leading to the conclusion that its value is underexploited. Kozlowski et al. [12: 37] state:

> Green fibrous plants provide valuable by-products such as seeds, waxes, fragrances, and pigments. These may be used as food, fodder, pharmaceutics, cosmetics, and body-care items. Especially important are linseed/hemp seed. They contain substances indispensable for our brain and nervous system as well as antisclerotic/anticarinogenic lignans and unsaturated fatty acids.

Flax products have been reintroduced in new configurations in the bio-composites arena, for building materials, vehicles, aircraft and furniture, as well as in the medical sector which is an achievement. Blackburn [1] notes the importance and impact of the development of synthetic chemical products for composites used in large amounts of products, and he points out the issues and concerns surrounding these non-degradable composites, made from non-renewable resources, which are consuming remaining oil resources. There is a move towards bio-composites based on natural fibres such as flax, jute and hemp, which are lightweight, strong, resistant to corrosion, and have good sound and moisture absorption. In order to define a material as 'biodegradable', it must be able to be 'broken down into simpler substances (elements and compounds) by a naturally occurring decomposer. For material to be regarded as 'bio' the full cradle-to-cradle lifecycle of the fibre or

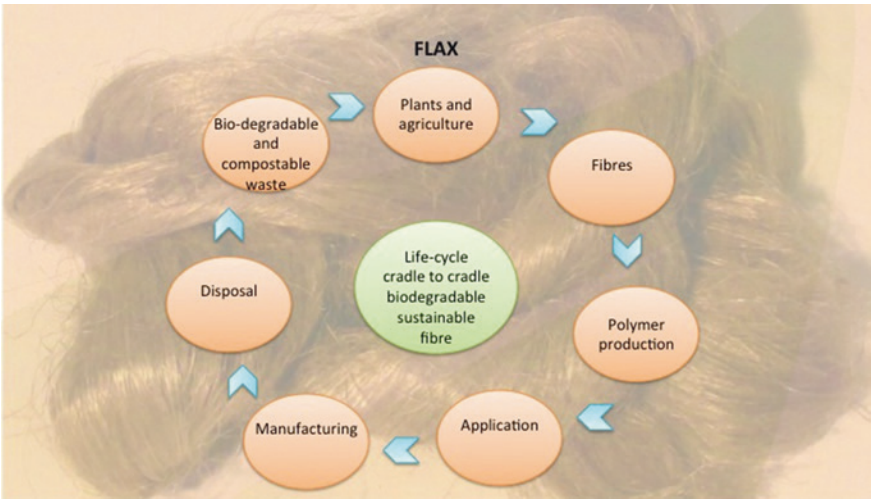

Fig. 1 Flax biodegradable fibre lifecycle (© August 2014, with kind permission of Carolyn Watt, University of Portsmouth, UK)

product must be taken into consideration (see Fig. 1). Innovative flax fibre applications are only now becoming apparent. For example, extremely diverse bio-composites can be mixed with natural fibres and/or coated in a variety of bio-resins to create a spectrum of new composite materials and applications for new luxury premium products with a cradle-to-cradle transparent supply and disposal chain.

1.1 ProjectFlax

To understand and address the issue of best practice production and consumption of materials, a multi-faceted approach is needed to inform all areas of the supply chain—the combination of arts and science collaborations enrich the research process and outcomes. ProjectFlax illustrates this approach by bringing together a transdisciplinary team of regional research centers in materials (Le Havre University, France); biomaterials, food processing and design (University of Brighton, UK); a small and medium sized enterprise (SME) (Liniere de Bosc Novel S.A, France) with experience in growing and manufacturing flax fibers and in the research and development of flax-based products; and academics with extensive expertise in biochemistry and characterization of flax materials (Rouen University, France). The partners were selected as they have complementary expertise in design, science, technology, engineering, mathematics and business (D-STEM-B) skills, as well as having advanced machinery and processing facilities used in the growing and manufacturing of flax.

The proposition that sustainability and social responsibility are key themes of new luxury are underpinned by the ProjectFlax research community, methods and development outcomes, suggesting that sustainability 'is rapidly becoming an issue of critical importance for designers and society as a whole' [24: 72]. Sustainability is not purely about sustainable environments, material goods and manufacturing, but also about developing and promoting wellbeing for people and communities to enhance quality of life. The consumer needs to identify not only with the narrative, but also with others in order to make sustainable choices. Johnson [11], a writer, speaker and freelance consultant specialising in behavioural change, sustainability and social innovation, argues that in order to change peoples' behavior surrounding sustainability it must hold meaning within their personal life. This view is further supported by Cox and Beland [4: 307]: 'The concept of sustainability suggests a growing concern for the long-term consequences of decisions, and it implies an increasing dissatisfaction with current practices'. Consumers are taking meaning from materials and product production, to give new values to goods and, in doing so, are beginning to understand the origins and ethics of products' journeys in terms of people, profit and planet.

The British and French artistic and scientific communities involved in ProjectFlax were brought together through the development knowledge exchange, new working methods, dialogues, and scholarly and practical materials development and process outputs, to successfully answer the project objective, which was to increase the value of flax for society. The team was able to learn from one another's research design, adding value to their own disciplinary practice and, in turn, took a holistic approach to the work over the project's three year period. Johnson [11] observes:

> If we are to effectively drive behavioural change, we need to locate our issue within people's existing value sets and priorities, rather than seek to extend their values sets to encompass our issue… Culturally, sustainability is a scientific issue and most behaviour change work is built on the assumption that people will attach as much importance to climate change, species diversity and resource depletion as the scientists do. It is essential therefore that when it comes to consumer behaviour change, we take their lives not our issue as a starting point.

It was therefore imperative to take not only a scientific approach to increasing the value of flax fiber, but a holistic approach incorporating the arts and humanities where applied research skills in packaging materials design, materials chemistry, engineering and characterization and analysis, biomaterials, food, fashion and environmental impact assessment tools were available. With a focus on transdisciplinary design research and collaborative working, ProjectFlax highlighted the importance of the use of transferable skills for applications of wellbeing and product design to give added value to the producer and consumer, contributing to a more authentic, transparent, effective and sustainable industry in the long term.

The resurrection of flax through the exploration of qualities such as its sustainable and wellbeing credentials offers the market a new form of desire and need. Innovation, research and development of the fibre properties of flax from the molecular scale to products and environmental impact shows advantages, such as

sustainability, over many of its natural and man-made rivals, which underpins our proposal of flax being a fibre central to the new luxury concept. Now, a contemporary view of flax is emerging and will become part of new luxury answering the needs of a new generation of consumers looking for quality, craftsmanship and societal benefit. The knowing consumer buys into a subcultural brand where he/she recognizes other knowing consumers from the same intelligent tribe. This chapter comprises selected case studies originating from transdisciplinary research undertaken as part of ProjectFlax. It aims to prove innovative applications for the flax fiber, to add to its cultural and societal value alongside its physical applications, situating it as part of new luxury.

2 Methodology

Using a holistic transdisciplinary approach among arts, science and business, the international ProjectFlax research team of 20 was able to use and share a range of research methodologies from their own disciplines to investigate numerous lines of enquiry, focusing on the concept of materials development from flax, resulting in a complex mixed method approach. The science methodologies combined case study, desk-based, laboratory, field study and quantitative methods involving collaboration with national and international organisations, both commercial and institutional. From arts they included narrative and observation, qualitative methodology, practice-based and practice-led studio and workshop research to push the aims and objectives and results as far as possible within the time and funds available. Dialogue between the disciplines around the findings and innovation was difficult at times due to the different languages and the disciplines used, such as chemical equations versus design drawing. Knowledge transfer and knowledge exchange in the UK and France played a key part in the studio, workshop collaboration and created new and innovative networks for research and development which have been sustained long after the project ended. The team published in a variety of scientific journals and the work was showcased at symposia and exhibitions in the UK, France and the 7th Textile and Bioengineering and Informatics Symposium, August 2014, Hong Kong.

The goal of the research was to restore the cultural and societal value of flax in its various applications through the concept of *new luxury*. The rationale behind the partnership was envisioned by Professor Sergey Mikhalovsky, materials chemist and principal investigator from the School of Pharmacy and Biomolecular Science at the University of Brighton, UK. Mikhalovsky realised that the interconnectedness of the flax supply chain, its history and chemistry, its significance in nature and the underlying sustainable narrative linked to product development would need a team with critical differences in their approaches from arts and science to innovate and think freely. The team was transdisciplinary in composition, including bio, polymer and materials chemists, agriculturalists, business, product and materials designers, professors, research fellows, post docs, post graduates

and undergraduates. Transdisciplinarity was introduced to the public by the Swiss philosopher and psychologist [20] who addressed the issue of relationships between disciplines in an academic context, purporting the notion of transdisciplinarity to create chemistry between unrelated disciplines that enable investigations and opportunities for collaboration in a third space beyond their respective contributions. ProjectFlax brought together different disciplines to create a range of approaches and solutions to environmental and human problems in order to develop ecological products and thus support the notion of an emerging new luxury based on product integrity.

3 Flax Applications

3.1 Flax in Fashion: Ethical, Responsible and Sustainable Clothing as New Luxury

The contemporary fashion and textiles industry has suffered from the emergence of 'fast fashion' where the retail mantra of 'pile it high, sell it cheap' clothing has created vast quantities of textiles waste [9]. It can also be argued that designer and luxury goods have suffered from the mass production of sophisticated counterfeit products and have achieved a throwaway status [21]. So how can designers, engineers and manufacturers differentiate their products and reinstate brand identity in the global marketplace? Brand differentiation, as is evidenced in the food industry, can come from responsible transparent ethical production, and manufacturing coupled with superior quality; therefore, in relation to flax, its history, innovative product possibilities and sustainable credentials are the essential qualities which underpin the concept of new luxury in future, imbibing products with a raft of values and differentiating these intelligent luxury brands from those of the past.

> Within the context of the contemporary global economic recession, our consumption of luxury is being questioned and indeed transformed with the notions of 'affordable luxury', 'sustainable luxury' and even 'luxury for less' suggesting a new discourse. At the same time the demand for luxury goods and services on a global scale is at an unprecedented level [6].

It is this concept of flax being an example of sustainable luxury when assessed from a socio-ecological-aesthetic-economic viewpoint, which places it at the forefront of a paradigm shift in the luxury market where sustainability is we argue the new luxury.

The luxury goods industry was worth an 'estimated €217 billion ($300 billion) in 2013' [19] encompassing clothes, leather goods, watches, jewelry, perfume and cosmetics where expensive items convey status to those who recognize the goods. Still the way we dress reflects our personality, our economic political and social standing and our status within our peer group, setting us apart from the crowd, defining us through our outward appearance, establishing a means of recognition

and of signaling to others like ourselves, epitomized in luxury fashion. Christian Dior, considered by fashion scholars to be an iconic designer of modern fashion said

> I am no philosopher but it seems to me that women and men instinctively like to exhibit themselves, which in this machine age, which esteems convention and uniformity, fashion is the ultimate refuge of the human and personal and the inimitable [22].

During the twentieth century, economic prosperity for many in the developed world propelled the desire for luxury consumption and the global market for branded goods grew exponentially. However, this century has seen the position of the luxury brand shifting in its value and narrative, not least due to the concerns of a new generation of consumers who are aware that over production and consumption of goods, financial inequity and environmental degradation are uppermost. The Internet has enabled brand transparency and information exchange in the market and, in the case of traditional luxury materials, the production problems, such as water table pollution in processing of leather or, in fur farming, animal cruelty or trapping endangered species such as big cats, have brought the luxury market and its non-monetary value into disrepute. In addition, the manufacture of fine goods such as beading and embroidery, often produced by hand, in a supply chain where processes and labor conditions can be difficult to monitor, remain an issue.

The purpose of this chapter was to reflect upon the future of the luxury brand and premium materials market in the light of the falling numbers of traditional customers who appreciate and invest in old luxury goods. The question is how would this market develop as the consumer becomes more discerning, intelligent and aware of sustainable issues i.e. people profit and planet and where aesthetics and exclusivity, repeated in every luxury brand store in cities across the globe, and are no longer enough to maintain customer loyalty and sustain sales, except perhaps in successful new economies? Regarding the burgeoning of the luxury goods brand businesses globally, Tom Ford, known for his turnaround of Gucci, says about luxury:

> It is like McDonald's: the merchandising and philosophy behind it is very similar. You get the same hamburger and the same experience in every McDonald's. Same with Vuitton. We helped to create that at Gucci. It was the right thing at the right time… And it's foolish to think that customers are not going to tune out, that they aren't as bored with it as we [the designers] are [22].

As in the retail sector, the recent twentieth century in the textile industry has undergone a significant transition. The market has polarized into cheap mass-market goods on the one hand, through to high-quality products on the other. The new research and development arena is in the transition from basic or luxury functions of those materials to those with specialized narratives and/or multifunctions to attract the intelligent consumer. The objectives of these high-quality narrative textiles, have resulted in the facilitation of a paradigm shift from traditional passive textile products into active textiles, which are able to interact with the consumer from a sustainable point of view.

> Linen has written itself into the ambitions of the luxury industry regarding sustainable development (the protection and development of the sources of high-quality raw

materials, and to protecting and preserving knowledge), and of design, fashion, interiors, soft furnishings, and the contract sector [15].

Sustainability is the new luxury when located in the flax narrative, the benefits of which are easily communicated to the consumer by the brand with honest authenticity. New farm mechanization and technical developments in processing of the fiber, yarn and textiles have improved and refined the materials for a wide range of high value markets. Understanding flax's technical properties through research and development made higher quality, defect-free textiles possible, which were wear resistant. The hollow fibers created textiles that breathed and provided installation in any season, regulating the body temperature in the summer as the fibers could absorb 20 % of its dry weight in moisture without feeling damp, and yet were comfortable in the winter. In addition, flax has non-allergenic and antibacterial properties (some surgical sutures are made of flax), antistatic properties, does not attract dust and is naturally resistant to moths and mildew. The fiber takes and fixes colour well, which improves and often deepens in tone as the fabric wears and the central cores of the fibers are exposed. Flax has an affinity for dyes requiring a minimum amount of dyestuffs and development of low-impact reactive dyes and fabric finishes such as wrinkle resistant treatments and enzyme finishes which respond to the demand for eco-designed textiles has been a priority, achieving OEKO TEX and GOTS accreditation [2].

In Europe the plant is sewn between March and April, taking 100 days to reach maturity; the blue flowers bloom in June and last for one day. The plant consists of a single stalk, about a meter high, from which 80 to 100 leaves sprout. It has equally long roots and is 100 % biodegradable. When flax is harvested it is not cut but pulled out of the ground so as to preserve the full length of the fibers contained in that stalk. In June to July, when the third of the length of the stocks have lost their leaves, it is pulled and laid on the ground in swathes or rows, one meter wide. The first processing, termed retting, is a natural biodegradation process of the stalks using wind and rain. The application of rain and sunshine from July to September, and the combined action of microorganisms and bacteria naturally present in the soil, ensure the fermentation needed to separate the textile fibers from the woody part of the stalk in the most sustainable and natural process. The fibers are extracted from the stalks' external envelope and the wood at the centre of the stalk is removed (called the shave). After harvesting, the long roots that have remained in the ground fertilize the soil and make it healthier, thereby giving flax its reputation as an excellent soil improver. Renewed in rotation every six to seven years, flax farming produces optimal soil quality, therefore increasing returns on the following crops of up to 20–30 %. The next step, scotching, is an entirely mechanical process that takes place throughout the year. During this process, the two types of fiber are separated, the long fibers (line flax) and the short fibers (the toe), as well as the by-products including the shave. Flax is also a carbon sink as, during its growth, the flax plant absorbs CO_2 released into the atmosphere where 1 ha of flax retains 3.7 metric tons of CO_2 annually, on a European scale this equates to 450,000 tons of carbon pollution avoided

through this farming contribution. Reduction in greenhouse gas emissions meets the requirements of the European Union and the Common Agricultural Policy, which promote a green Europe and fulfils another green requirement, as it is an economic plant when it comes to water consumption. Flax is grown in countries with the temperate climate, so it requires no irrigation – just rain. Natural resources are sufficient to feed the plant, this needs little nitrogen, little cultivation, and requires very little input put of fertilizers and pesticide products to preserve its natural resistance. Compared with cotton, for example, flax requires five times less input also preserving the quality of groundwater. Flax is a zero waste fiber where everything is either used or processed for textiles, paper, matting, flax seeds, oil, varnishes, linoleum, gardening installation, animal litter, compost and beauty products. The fiber and its derivatives are an ideal material for developing high-performance bio composite and for medical applications, all products made from it can be recycled and it is 100 % renewable. Quality linen handle improves in suppleness and softness the more it is washed because the pectin that binds the fibers in the growing phase dissolve more every time it comes into contact with water; therefore, the fabric becomes gradually a luxurious material as it ages and, as it is the strongest natural textile fiber, it is long-lasting.

Traditionally flax was a luxury fiber, sought-after by the aristocracy 'put bussos around her limbs, prepare her bed with royal linen pay attention to the white linen of the lingerie' [23] this fabric known as bussos was cited in The International Standard Bible Encyclopedia which denoted a variety of flax, where the cloth woven from it was very delicate, soft white or yellow and very expensive due to the effort and time involved in growing, processing, spinning and weaving the material by hand. The cloth was highly sought-after and produced in the Nile Valley, it was known for its extreme fineness, which played a key part in Egypt's economy, because like grain it was used as currency.

The Chairman of the Comité Colbert, [15] said of linen:

> Know-how and its transfer from generation to generation are the very foundations of the luxury industry. A living heritage that we nurture, either through essential on-going training of the artisans… or by acquiring other highly qualified businesses or workshops (as Chanel has done several times).

Linen is also a premium material in that it is a natural polymer and evidence exists that it was used in one of the first composites found in the armor of Alexander the great 256–2323 BCDE (Duval 2009). Layers of laminated linen cloth (Pliny) enabled mobility on the battlefield and was made of 11–20 layers of linen fused with a linseed oil based bonding agent and compressed during the dying process with performance factors similar to that of Kevlar. Flax compares with glass and carbon: in stiffness, they are equal to glass and about a third of carbon but, when the density is taken into account, flax performs better than glass fiber. Furthermore, when looking at the specific stiffness in bending, the values of flax approach source of carbon fibers [2].

Linen spun from flax is a lustrous material with a soft, flexible handle and can be woven into superfine decorative and functional fabrics. Linen is considered to be superior to, and more durable and sophisticated than, cotton and remains an expensive status symbol understood by affluent consumers who value its characteristics and green credentials, and recognize and appreciate others who wear it and belong to the same 'club'.

Linus in Latin means *most useful flax* and the scientific name emphasizes just how much the plant was respected, providing soil improvement, natural biodiversity, materials, food and more; it is a plant with societal, environmental and economic credentials, steeped in history. Nevertheless, even though linen is synonymous with particular contemporary labels (such as Armani Italy) and does well if the trend is right or it is seen on catwalks as a sophisticated fashion classic, its market share is diminishing except for predicted growth until 2020 in the BRIC countries (Russia, India and China). There is a luxury business opportunity to develop high quality limited edition products for those consumers who understand its sophisticated message, which set them apart from the rest. It is not unimaginable to have a whole store, e.g. 'The Flax Shop', with products developed entirely from a sustainable source such as flax. These signs denote and communicate an understanding of a narrative and meaning of the material, which are key components of, and define, the new luxury concept and consumer. Importantly, as consumers become increasingly aware of green issues and desire products produced by best practice, the brand name may become less important as the material and its production credentials from a sustainable point of view, become the new luxurious 'must have'.

3.2 Flax in Agriculture: Food and Medicine Become New Luxury

Flax is not only a source of fibre for fabrics and composites but the plant also has a long history in the food and pharmaceutical industries. Today, cold-pressed flaxseed oil and ground flax seeds are increasingly sold as health foods as awareness of health issues such as obesity and diabetes drive us towards healthy eating and improved lifestyles. The perception of eating a natural diet, with plenty of whole foods and organic produce, is quickly becoming the new luxury in food terms, creating a hierarchy of consumption and price when compared with those who use cheaper, pre-packaged and processed, and mass produced food. One of the ingredients attracting the most interest is polyunsaturated fatty acids (omega 3, 6 and 9), which have anti-oxidant effects with a potential to protect cells from the free radicals generated through metabolic processes. Flax has an exceptionally high lignin content, the principle one being secoisolariciresinol diglucoside (SDG) which acts in a similar way to omega fatty acids. It has been suggested that SDG has beneficial hormone-modulating qualities that could prevent tumor

formation and prevent the generation of new blood vessels in existing tumors. Like polyunsaturated acids, SDG can also quench cell-damaging free radicals. Flax seed can be added to most foods in cooking in various forms to increase its nutritional value, due to these qualities which will enhance human and livestock feed, markets for flax seed are 'expected to increase owing to the unique properties of this ancient crop' [17: 889].

Research developed as part of ProjectFlax in the UK on lignin produced from flax seed has shown that the component SDG is non-toxic to renal cells in the flax plant (the most sensitive to extraneous factors) in a laboratory model. Professor Mikhalovsky (School of Pharmacy and Biomolecular Sciences, University of Brighton) is currently investigating whether SDG could protect cells when they are exposed to the destructive effects of free radicals, which can lead to disease. In addition, encouraging data from the project has demonstrated the inhibition of autophagy in hela (tumour) cells in the laboratory by SDG. Autophagy is a mechanism whereby cells induce their own enzyme-mediated digestion. In normal circumstances this process can prevent the onset of disease (e.g. cancer) by removing abnormal cells from the body. However, in established tumour cells, autophagy can compromise drug treatments by shielding neighbouring tumour cells from chemotherapeutic drugs. Thus, careful targeting of anti-autophagic agents (such as SDG) could assist in anti-tumour chemotherapy. Currently, chloroquine (a drug used in the treatment of malaria) is being tested in clinical trials for this purpose. However, SDG may be more effective since it is able to block autophagy at two different stages of the process compared with one for chloroquine. Researchers have also shown that SDG from flax is an efficient binder of metals. Using mass spectrometry to elucidate binding constants for SDG against target metals, Dr Flavia Fucussii's findings (School of Pharmacy and Biomolecular Sciences, University of Brighton) indicate that dietary flax SDG could have sufficient metal affinity properties for extracting accumulated toxic heavy metals from the body, such as lead, mercury and aluminium. Toxic heavy metals are suspected of causing a variety of threatening conditions including thyroid issues, heart disease, neurological conditions and autism. The inclusion of flax in a nutritionally-balanced diet could therefore have a number of health benefits.

3.3 Flax in Wellbeing: A Return to Natural Healing Materials as New Luxury

Another area for ProjectFlax has been to evaluate the potential of the flax plant using innovative fabrics, materials and coatings for 'smart textile' applications. Smart materials are ever more apparent through responsive and adaptive fibres, combined with technology employed to monitor vital signs. These fabrics have a multitude of functions such as communicating data, processing information, sensory functions in healthcare, and fabrics that carry medicine, restrict and control

pressure on limbs, and can be used internally in the body as a scaffold. In hospital textiles, flax has many applications for implants, tissue engineering, hygiene and healthcare products, packaging, bandages and wound dressings, hospital sheets and staff uniforms. 'As the global population continues to increase, the prevailing demographic profile moves towards great life expectancy and an ageing populace whose expectations for enhanced healthcare continue to grow' [13: 4]. Previously, smart and performance textiles were developed through space and military research; however, there is an increasing market for these innovations in the civilian population.

Within ProjectFlax, pharmacy and biomolecular sciences research teams at the University of Brighton, led by Dr Iain Allan, found that when flax seeds are exposed to fluids they have the fascinating property of exuding copious amounts of gel-like mucilage, which is a diverse mixture of polysaccharides and proteins, quite similar in nature to human mucus. Mucilage possesses an abundance of charged groups of a molecule within its structure, which makes it a good candidate for loading with chemotherapeutic drugs (with opposing charge), which can be slowly released at a liquefied appropriate target site within the body. The research team has focused on the creation of mechanically stable mucilage hydrogels, which can be loaded with active agents such as antimicrobial agents or anti-inflammatories (Fig. 2). Such gels can be applied to the mucosa (e.g. oral or vaginal) to deliver a slow-release chemotherapeutic dose. This could provide direct therapy to damaged mucosa and also offers the capability to deliver drugs systemically, bypassing the liver.

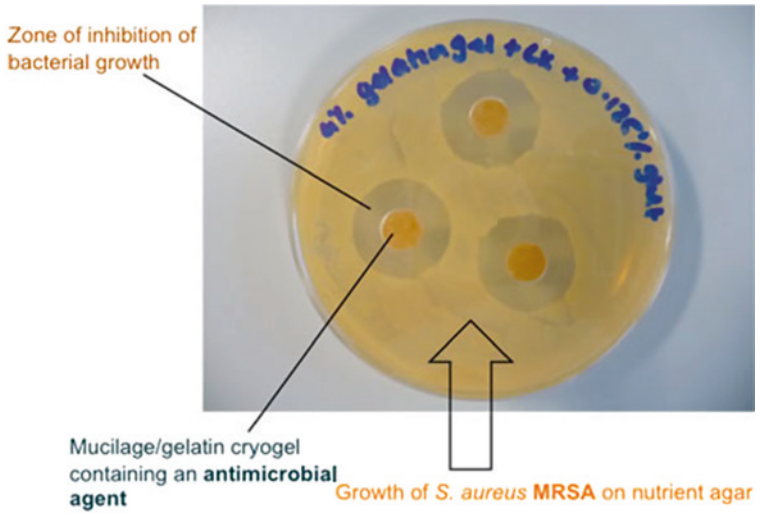

Fig. 2 Demonstrates the ability of an antimicrobial agent to diffuse from the gels and prevent bacterial growth (shown by the clear zone surrounding the gels created from flax mucilage) (© Spring 2012, with kind permission of Dr Iain Allan, School of Pharmacy and Biomolecular Sciences, University of Brighton, UK)

Mechanically stable mucilage-containing gels in the form of cryogels are highly absorbent, interconnected structures with a sponge-like morphology that are formed by freezing a pre-gel formulation. As illustrated in Fig. 3, this sponge-like gel has a porous structure, with the pore walls here represented in yellow. The mucilage portion of the wall can bind antimicrobial agents, which will be controllably released at the wound site. Mucilage cryogels have a number of potential applications. These cross-linked materials have good mechanical properties enabling their make up to take the form of a patch (Fig. 4) that when applied can closely follow the contours of the skin. The patches can be infused with active drugs; their highly porous nature also provides an ideal environment for infiltration with human cells. Current work at the School of Pharmacy and Biomolecular Sciences, University of Brighton, includes evaluating the patches and cryogels for use as dermal tissue regeneration scaffolds. These can potentially be used to treat burns victims and reconstruct skin damaged by chronic ulcers. The intention is to screen the cryogels and woven textiles as carriers for application to the skin surface.

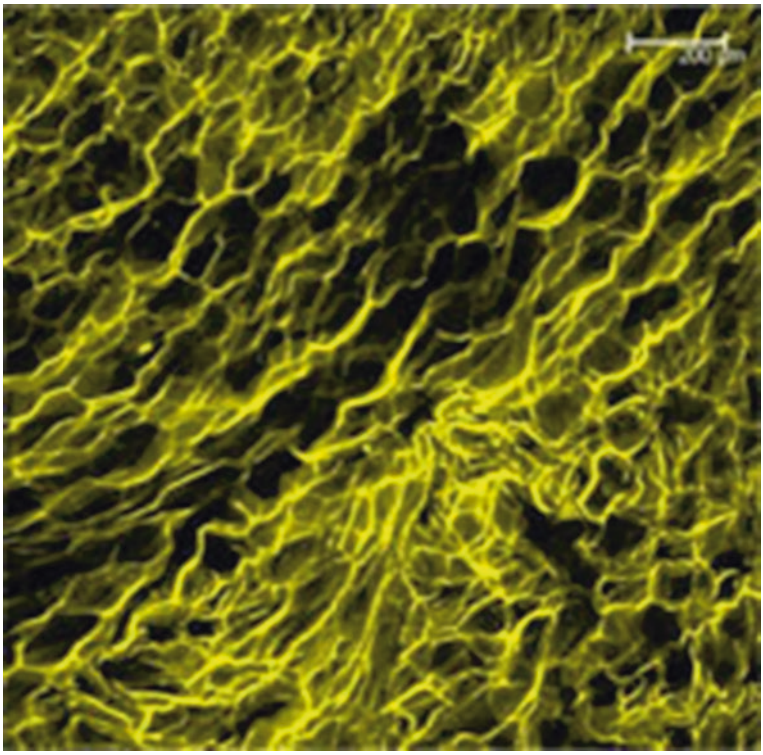

Fig. 3 A confocal laser scanning microscopy image of a mucilage/gelatin cryogel (© Spring 2012, with kind permission of Dr Iain Allan, School of Pharmacy and Biomolecular Sciences, University of Brighton, UK)

Fig. 4 A prototype mucilage/gelatin hydrogel patch (© Spring 2012, with kind permission of Dr Iain Allan, School of Pharmacy and Biomolecular Sciences, University of Brighton, UK)

These cryogel films were inserted into, and combined with, knitted and woven fabric structures (Fig. 5) with the aim of creating wound dressings with antimicrobial agents. Research has taken place into the infusion of flax fibres with antimicrobial agents for the production of wound dressings. Flax fibres have a porous structure, with absorption and strength properties superior to those of cotton,

Fig. 5 Knitted cryogel sample (© March 2014, image by Carolyn Watt, with kind permission of Sophie Forster, MDes Knitwear student, University of Brighton)

ensuring maximum efficacy when the antimicrobial agent chlorhexidine was added to flax fibres and allowed to penetrate into the fibre pores. After thorough rinsing, the fibres were found to have been saturated with both bacteriostatic and bactericidal activity against *Staphylococcus aureus* and *Pseudomonas aeruginosa*, two key bacteria responsible for serious infections. There is a growing concern that antibiotics are losing their potency. A recent World Health Organization report [25], *Antimicrobial resistance: Global report on surveillance 2014*, has revealed that antibiotic resistant bacteria pose a 'serious, worldwide threat to public health' and urges that we need to 'take significant actions to improve efforts to prevent infections'. *Staphylococcus aureus* is a bacteria that can cause potentially life-threatening local and systemic infections. Methicillin-resistant *S. aureus* (more commonly known as MRSA) is well known as a principal cause of hospital-acquired infection characterised by broad-spectrum antibiotic resistance. The Centres for Disease Control and Prevention [3] state that 'people who have MRSA germs on their skin or who are infected with MRSA may be able to spread the germ to other people. MRSA can be passed on to bed linens, bed rails, bathroom fixtures and medical equipment'.

Photodynamic therapy (PDT) is a potential alternative to antibiotic therapy and is being investigated as a treatment for antibiotic-resistant bacterial infections. PDT combines the application of a non-toxic photosensitive dye with exposure to light of a specific wavelength, resulting in the generation of reactive oxygen species, which are lethal to bacterial cells. In research and development, the ProjectFlax team has demonstrated that dyed flax fibres can successfully be used for lethal photosensitisation of drug-resistant bacteria. Flax fibres were autoclaved,[2] soaked overnight in metachromatic dye toluidine blue O (TBO) and dried. The flax fibre is able to absorb these light sensitive dyes with a greater capacity than cotton, the most commonly used material. The fibres were then exposed to MRSA so that the bacteria adhered to the outside of the fibre. The fibres were exposed to red light for one hour. Exposure of TBO-infused fibres to light resulted in a 99 % reduction in bacterial viability of MRSA. No antibacterial effect was found when flax fibres dyed with TBO were kept in the dark, or when fibres were exposed to light in the absence of TBO. The microbial burden on natural fibres, such as those found in bed linens, could be reduced by infusing them with photosensitising agents and exposing them to a controlled light regime. This application could reduce bacterial contamination and infection on bed linen and patients' clothing. Ultimately, these materials could shorten the time required for recovery of patients, so reducing the financial burden on healthcare providers and improving quality of life for patients. This case study illustrates added value design for the consumer, contributing to improved outcomes for health and wellbeing to the end user. By building on traditional health applications of flax, the fibre is modernised for today's healthcare challenges.

[2]An autoclave is a pressure chamber used to sterilise equipment and supplies by subjecting them to high pressure saturated steam at 121 °C (249 °F) for around 15–20 min, depending on the size of the load and the contents.

The use of flax in healthcare is not only innovative, but also sustainable. Transdisciplinary methodology and collaborative working within ProjectFlax was necessary in order to develop such medical applications. Like the health food and fashion and textile industries, there is a growing movement towards naturally-derived and sustainable materials within medicine, proving flax to be the new luxury across each of these fields.

3.4 Flax in Design: The Results of Innovation in Addressing Physical and Cultural Issues as New Luxury

New luxury embodies the concept of closed loop design, with an energy efficient and zero waste manufacturing, retail and disposal chain, and where environmental and human ethics are fundamental, to create a circular economy through a holistic supply, production and disposal approach. The role of design, underpinned by arts and design education, is fundamental to the notion of new luxury, combining sustainable philosophies where the informed designer, who creates the desire for a luxury product, could contribute to societal change by having a deeper knowledge of, and make better choices in, materials, processes and economics.

Farrer and Finn [7: 36] observe: 'Fashion textiles design has much to answer for in contributing to the problems of unsustainable practices in design, production and waste on a global scale'. This is due to designers fueling the desire and need for customers to constantly buy more fashion garments, which are often quickly discarded, in good materials at ever cheaper prices. 'However, designers within this field also have great potential to use their extensive skills to contribute to practical solutions' [7: 36–37].

The role of the designer is critical, as often the problem or issue is the result of poor design. Thus, solutions to unsustainable practices can be 'designed into' a self-sustaining supply and demand model, communicating the issue but also the solution to the end user. For example, we should use the luxury food industry as a model, where in organic sustainable farming all parts of a slaughtered animal and its by-products are used. Thus, luxury food producers have realized that there is a philosophical brand narrative to promote value and market differentiation and secure consumer loyalty. So, too, new luxury can be defined by sustainable practices appealing to a new type of consumer, one who relates to a holistic, and zero waste, circular economy production process which defines the new luxury concept. Flax fiber has the credentials for this new luxury profile. Product and medical materials innovation using flax may encourage the exploration and exploitation of this material in a range of applications developed through design, engineering, chemical and agricultural technologies.

New luxury also takes into account designing for the appropriate product lifetime. Fashion, by definition, creates built-in obsolescence and waste, visible in the 'churn' of new products in retail which is a direct result of over manufacturing of goods for an unsatisfied consumer, often using long lasting oil-based materials or

natural materials unethically produced, with their associated adverse environmental impacts. How can this be termed luxury? Whereas using a sustainable, organic fiber such as flax, which has a light ecological footprint in processing and is a versatile research and development material for the body and built environment could define a new consumer and new luxury. Flax fibre has been used in products for health, sport, wellbeing and leisure, in the automotive industry as well as in the design and conception of both interior and exterior cladding and soundproofing for buildings. The material can be allowed to biodegrade when no longer required or can survive for centuries, should the application require, this is the new luxury with a value added product lifecycle that discerning consumers seek. According to Wahl and Baxter [24: 82]: 'The necessary shift towards more appropriate and sustainable modes of participation requires that design and education contribute to a widespread increase in social and ecological awareness through trans-disciplinary design dialogues'. Innovation in education enables practical and holistic solutions to be discovered.

3.4.1 ProjectFlax Design Competition

Flax fibre is now being re-examined and contemporised by designers and scientists in order to meet the demands of modern culture and is illustrated through work undertaken by staff and students at Le Havre University, Rouen, France and University of Brighton, UK. The staff and student participants in ProjectFlax, showcased in this section, were from fashion and textiles, design and craft, engineering, pharmacy and biomolecular sciences and agricultural disciplines.

In January 2011, University of Brighton students from the fashion and textiles, design and craft courses within the Faculty of Arts, and from the Schools of Environmental Engineering and Pharmacy and Biomolecular Sciences competed in a flax competition and were given a brief by the co-investigator and first author of this chapter: 'It is the year 2050. Resources are scarce. Sustainable materials are at the heart of our existence…'. The students were asked to develop a range of materials using flax fibers, fabrics and resins in various forms for any applications for 'blue sky thinking' conceptual ideas, with the potential to develop products, functions or services, real or virtual for the flax fiber. The relevance of the brief to the various disciplines was to create a community of learners who will spearhead the new luxury market underpinned by sustainable design principles [8].

The successful integration of this live teaching project within the curriculum in 2011 enabled a change in educational approach and discourse, with a view to curriculum development and teaching in the community of learners. Textile design students worked with team members from science and arts from the University of Brighton to combine the sustainable and nutritional benefits of the flax plant into a complete range of packaged foods. The competition allowed students to consider materials and fibers outside of their discipline of textiles and to act as a catalyst in teams outside their comfort zone. Combining the idea of bio-plastics, resins and

flax's health benefits, the students' winning concept, 'Nature's Shell', consisted of edible packaging aimed at adult snacks, microwavable meals and the three stages of weaning in toddlers and preschool age children (Fig. 6).

In 2012, the ProjectFlax competition ran again and the winning student team created an entire brand named 'Flax Pack', which captured the versatility of flax fibers in product design (Fig. 7), leading to a more sustainable range for the music festival-going audience. This project targeted food packaging and edible products, but also biodegradable tents, chairs and ponchos, simultaneously addressing the issue of the huge amount of waste generated at festivals in fashion, textiles, composites, foodstuffs and agricultural impacts. These students, as future designers, expressed their view of the new luxury, and were able to modernize the use of flax fiber in order to meet today's cultural and societal expectations.

In 2013, the competition was integrated with the subsequent INTERREG project Building Research and Innovation Deals in the Green Economy (BRIDGE) and was open to University of Brighton students across the two disciplines: design and craft; and fashion and textiles. The winning project focused on new luxury, with an emphasis on closed loop manufacturing in a particular rural geographical location, centred on sustainable dye processing and waste issues from the wine-making industry.

Fig. 6 'Nature's Shell' poster concept by Carolyn Watt (© January 2011, with kind permission of Carolyn Watt, University of Portsmouth, UK)

Fig. 7 'Flax Pack' student project example (© January 2012, with kind permission of University of Brighton student team)

3.4.2 Undergraduate Module

ProjectFlax informed the undergraduate module entitled 'Material and its Form—Flax 2012'. In this module students were able to work with flax fiber in order to find new material methods and applications for flax in woven form. Their methods ranged from cutting, tearing, burning, immersing in water and freezing techniques, combined with the use of resins and glue mixes exploring molding and stiffening of the fabric. Many of the conceptual results were realized through the use of computer aided design (CAD) and hand drawn designs. Many students integrated the use of sewing techniques and traditional craft-making methods, resulting in architectural temporary shelters and protective material designs that pushed flax fibers and fabrics to their limits. Layered flax fibre was resistant to piercing and fabrics were extensively tested, using glues to heighten the rigidity of the material. Taking inspiration from Mongolian outerwear lined with waste flax, wool and linen as body protection, a winning project developed the material concept of flax as a sustainable alternative to the synthetic fibre Kevlar®. The designer created a prototype garment and tested its stab proof properties.

ProjectFlax offered students the opportunity to share knowledge, ideas and techniques in open discussions and tutoring sessions with peers and staff members from a variety of disciplines. This created a new experience for students to experiment with new materials and ideas in order to increase the value of flax and raise awareness of design issues surrounding sustainability.

3.4.3 Furniture Design

Driven by a motivation to design products based on ecologically sound principles of material selection and production, Dr Jyri Kermik, lead academic at the University of Brighton in the Department of Design, was involved latterly in ProjectFlax, investigating cultural archetypes and regional material resources to facilitate new luxury in design innovation. Kermik's international design presence is founded on expertise in materials technology, sustainable and environmental concerns, and experimental design applications. His research developed a new material composite prototype which he called PlyFlax. This combined fine plywood bonded with flax fabric, vacuum formed into an organic furniture design using minimal materials. This ecological flax material research project and chair design began with an exclusive invitation to contribute to the sustainable international 2012 EcoDesign show held as part of Helsinki Design Week and World Design Capital 2012, which offered a key meeting point and showcase for the design community. Kermik's research into flax and plywood experiments aimed to demonstrate the potential of regionally grown natural fibers for future design applications. This combined the advantages of composites with the enhanced performance of 'stressed skin' structures normally associated with material innovation in early aviation, led in Europe by the Estonian manufacturer Luterma. Interlocked layers of birch veneer, with their own inherent structural strength, are further reinforced with a skin of flax fibers allowing thinner plywood shells without compromising their strength or flexibility. Flax fibers, woven into a fabric sheet, perform in a similar way to glass/carbon fibers. The strength and viscous-elastic properties of natural fibers, and their visual quality, are captured and embedded within a matrix of bio-resin, a type of biodegradable glue made from organic components including flax. The ergonomic concept of the 'Woven Wind' (Fig. 8) expresses a design metaphor adopted from Japan, where flax is referred

Fig. 8 'Woven Wind' (© Summer 2012, with kind permission of Dr Jyri Kermik, University of Brighton, UK)

to as that which encapsulates both the sustainable qualities of the materials used as well as the natural movements of the materials used in the construction of the PlyFlax recliner, explored during the design process.

4 Conclusion

The chapter tells the narrative of the flax fibre, its importance through history as a valuable crop for materials for the body and built environment, using ProjectFlax as the focus for an international and transdisciplinary research and redevelopment team which aimed to reposition flax as a premium and new luxury fibre for the future. Through discussion of a selection of case studies from the UK and France, during the three year project the flax research team generated an array of innovation possibilities relating to arts and science applications for economic development. These were high value tailor-made inventions for both human and environmental wellbeing, underpinned by the sustainable agenda of people, profit and planet. Flax R&D was discussed in relation to the design of ethical, responsible and sustainable clothing, leading to the notion that these philosophies would define new luxury. Flax in agriculture reinforced the idea that foods and natural effective medicines would become new luxury at a price and, seeing a return to natural healing materials, flax will be viewed as new luxury from a D-STEM-B combined applied research innovation perspective. Finally, flax in design shows the results of innovation in addressing physical and cultural issues as new luxury.

Acknowledgements This work is funded by INTERREG IVA (South) project 4044 ('Flax: increasing its value for society'/'Le lin: augmenter sa valeur pour la société'). Led by principal investigator Professor Sergey Mikhalovsky, the co-investigators were: Dr Lyuba Mikhalovska, Dr Cressida Bowyer, Dr Maria Diakoumi, Dr Matthew Illsley, Dr Elena Sazhina, Dr Irina Savina, Dr Flavia Fucassi, Dr Joan Farrer (University of Brighton UK); Laurent Bizet (Le Havre University, France); and Beatrice Potez, Claudine Morovan, Davy Duratti (Liniere de Bosc Novel S.A, France).

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