› Burberry Material Futures Research Group

Scoping Project Summary of Reports and Exhibition Catalogue

The newly established Burberry Material Futures Research Group (BMFRG) at the Royal College of Art aims to inspire creativity and pioneer more sustainable materials and techniques in the UK creative industries.

The BMFRG takes a systems approach to materials research, thereby proposing new realities that re-couple use of material resources to human wellbeing and economic development, in order to help society transition to a more sustainable existence. The systems approach integrates three main themes: Sustainable Future Materials, Sustainable Future Manufacturing, and Sustainable Future Consumer Experience.

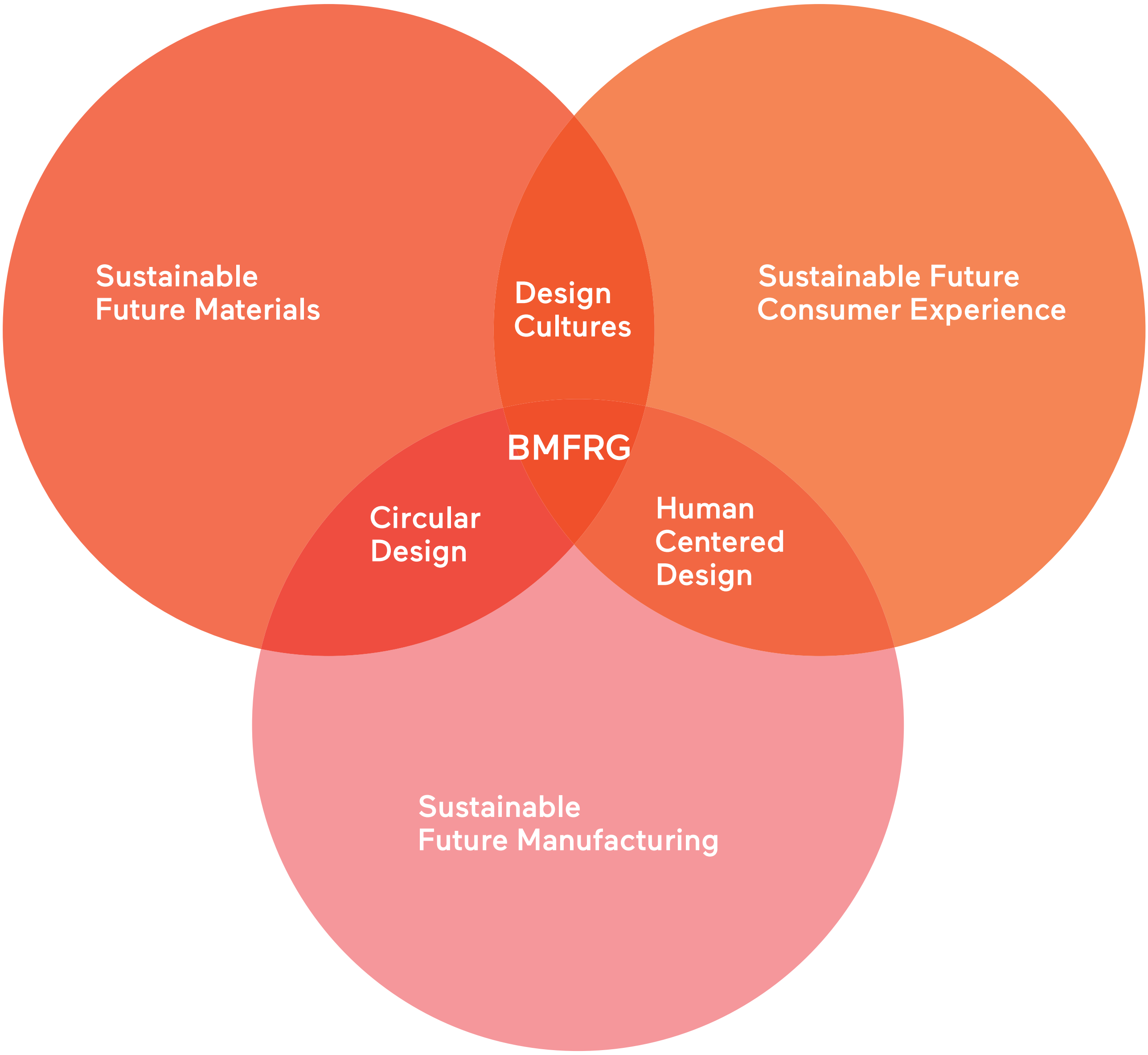
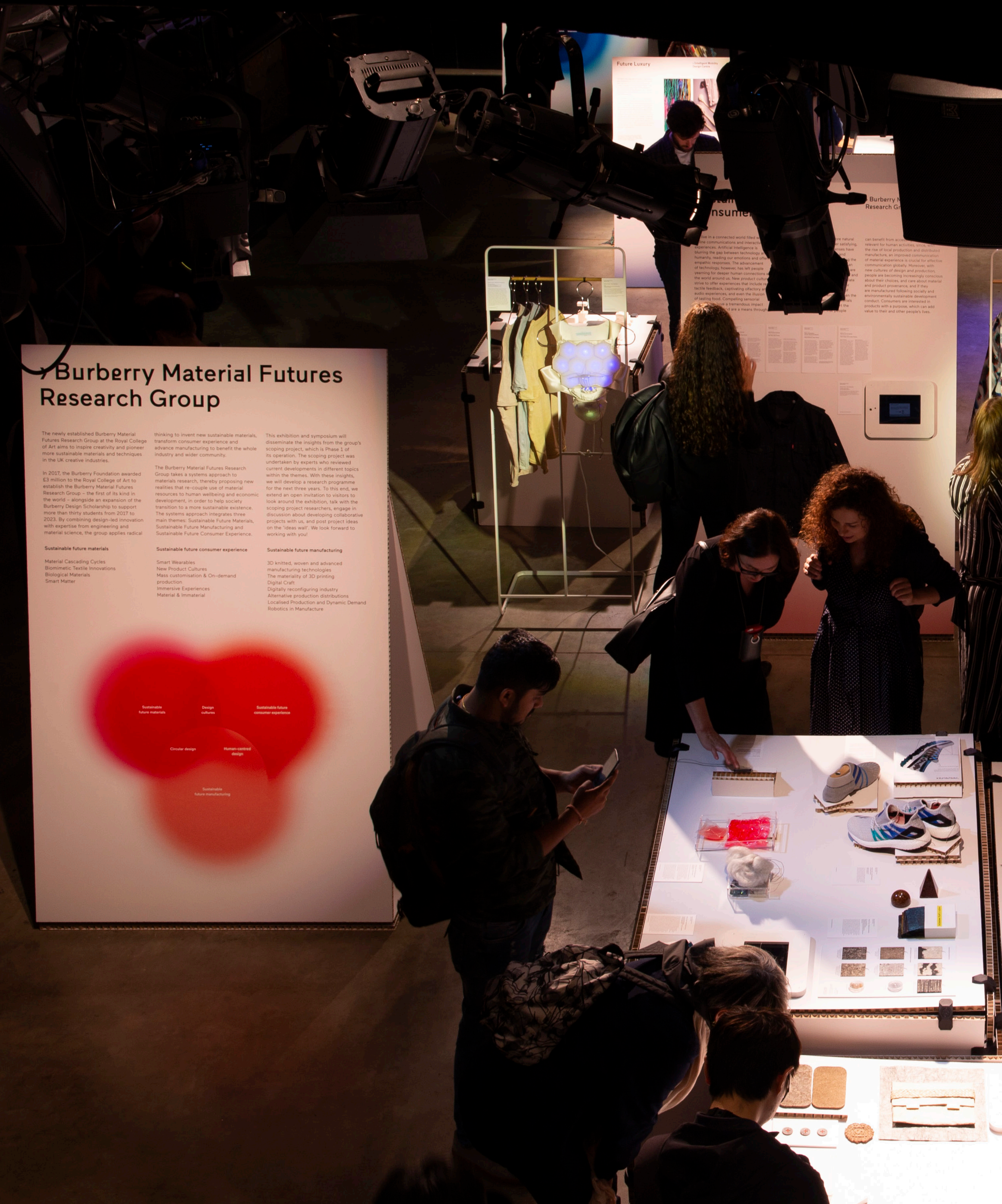


Figure 1. The three themes of BMFRG presented in a Venn diagram

Fig. 2 Design < > Research. Exhibition of scoping project outcomes during the London Design Festival 2018. Village Hall, Battersea Power Station.
Credit: Sotiris Gonis



Burberry Material Futures Research Group
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In 2017, the Burberry Foundation awarded £3 million to the Royal College of Art to establish the Burberry Material Futures Research Group – the first of its kind in the world – alongside an expansion of the Burberry Design Scholarship to support more than thirty students from 2017 to 2023. By combining design-led innovation with expertise from engineering and material science, the group applies radical thinking to invent new sustainable materials, transform consumer experience and advance manufacturing to benefit the whole industry and wider community.
The Burberry Material Futures Research Group takes a systems approach to materials research, thereby proposing new realities that re-couple use of material resources to human wellbeing and economic development, in order to help society transition to a more sustainable existence. The systems approach integrates three main themes: Sustainable Future Materials, Sustainable Future Manufacturing and Sustainable Future Consumer Experience.
This exhibition and symposium will disseminate the insights from the group's scoping project, which is Phase 1 of its operation. The scoping project was undertaken by experts who reviewed current developments in different topics within the themes. With these insights, we will develop a research programme for the next three years. To this end, we extend an open invitation to visitors to look around the exhibition, talk with the scoping project researchers, engage in discussion about developing collaborative projects with us, and post project ideas on the 'ideas wall'. We look forward to working with you!
Sustainable future materials
Material Cascading Cycles
Biomimetic Textile Innovations
Biological Materials
Smart Matter
Sustainable future consumer experience
Smart Wearables
New Product Cultures
Mass customisation & On-demand production
Immersive Experiences
Material & Immaterial
Sustainable future manufacturing
3D knitted, woven and advanced manufacturing technologies
The materiality of 3D printing
Digital Craft
Digitally reconfiguring industry
Alternative production distributions
Localised Production and Dynamic Demand
Robotics in Manufacture
Sustainable future materials
Design cultures
Sustainable future consumer experience
Circular design
Human-centred design
Sustainable future manufacturing
Future Luxury

Fig. 3 Design < > Research. Exhibition of scoping project outcomes during the London Design Festival 2018. Village Hall, Battersea Power Station.
Credit: Sotiris Gonis

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Sustainable Future Materials

Scoping Experts: Thomas Leech, Veronika Kapsali, Sara Robertson, Helene Steiner and Thomas Meany

Fig. 4 Design < > Research. Exhibition of scoping project outcomes during the London Design Festival 2018. Village Hall, Battersea Power Station. Credit: Sotiris Gonis

Our material world is exhausted by indiscriminate use. The sustainability concept is likewise wearied by excessive association with environmental threats and demands. In the world of materials, however, sustainability brings hope, with the rise of alternatives to escape depletion of natural resources and to help restore and/or maintain ecological balance. Indeed, where sustainability is not an option, we do have choices when it comes to materials and processes. The directions highlighted in the scoping reports are positively aligned with a Circular Economy view, that is, such alternative routes produce useful materials that are not dependant on continued mining of our planet's finite resources. Indeed, the list of examples of Sustainable Future Materials is extensive, therefore we classify this multiplicity of answers through three overarching themes:

Material Creativity

Processes of making, characterising and shaping materials are traditionally associated with material scientists and engineers. Recently, designers and artists, thanks to their sensibilities, and driven by social and environmental concerns, have started experimenting with unusual resources, as well as forms of assembling material ingredients into novel composites, and are

Material Circularity

A Circular Economy is an alternative to a traditional linear economy (make, use, dispose), in which resources are used for as long as possible, extract the maximum value from them while in use, then recover and regenerate products and materials at the end of life.

Material Choice

'Cascading cycles' materials (biological and technical material development, also working with waste and local, potentially yet undiscovered/unexplored, resources that could help maintain natural and cultural heritage), Bio-engineered materials (for example, fungi, bacteria, algae, etc.; also, working on diverse kingdoms and scales can take us to new frontiers of materials), Biomimetic materials (observation of materials and mechanisms in nature comes as a great tool to derive sustainable alternatives), and Smart Matter (highly functional materials, through technical or biological routes, can also diversify and/or extend the life of products).

Fig. 5 Malai Vegan Leather (right) Chipsboard (left) Credit: Sotiris Gonis

Fig. 6 Speedo's Fastskin and Sharklet Credit: Sotiris Gonis

Fig. 7 Shoey Shoes by Thomas Leech Credit: Sotiris Gonis

Fig. 8 MiMu Glove by Rachel Freire Credit: Sotiris Gonis

Biological Materials

Scoping project author: Helene Steiner

A revival of biomaterials that have actually been used by mankind for millennia, such as chitin (shells), cellulose (plant/fungi) and gelatine (bone) are now making their way into novel materials and products design. This is happening hugely through initiatives that attempt to reposition residues (by-products) as resources by exploring possibilities for agro, industrial, retail, and consumer waste.

While much of industry efforts are focused on remediation of current environmental impact by the fashion sector, we will see an emergence of materials that substitute more traditional materials, but with a lower social and environmental impact. An example case is the leather substitute mycelium. Mycelium constitutes the main, vegetative, portion of a fungus, formed of networks of branching microfilaments containing mixtures of cellulose and chitin. These interlinking branches can form impressively strong structures. The manufacturing process involves combining waste materials (agricultural/plant based) with mycelium (vegetative fungus). This mixture is placed in moulds/trays and the mycelium grows to occupy the mould and forms the desired shape. The process is reported to take one week. Ecovative, based in the USA, has emerged as the leader in manufacturing with mycelium. They have developed applications in foam and bulk material development but also in textiles. Their product “Mylo” has been used by Bolt Threads in the development of a leather substitute, Mylo Bag which was pre-sold on Kickstarter during summer 2018. Another US based company, Mycoworks is developing a leather substitute also using mycelium. It is also possible to grow pure mycelium, which leads to textile or rather skin like materials, as can be seen in the case of MycoTEX, created by the designer Aniela Hoitink.

Another example is the animal-free and 100% biodegradable wool WOOCOA, PETA & Stella McCartney BioDesign Challenge Winners. Achieved through a combination of hemp and coconut fibres, which are then treated with enzymes extracted from oyster mushroom as a finishing for softness. The material was created by students from La Universidad de Los Andes, Colombia.

Additionally, progress is noticed in the field of engineered materials, with specific emphasis on genetic modification of organisms responsible for the production of natural materials and organic compounds. Progress in this field has been rapid and is accelerating, and examples include hybrid reactive materials, which are materials produced using a genetically modified organism which incorporate an interactive element, for instance electrical or mechanical feedback. This approach opens ample room to go much beyond substitution of traditional materials, to work towards capitalising on the unique properties of these emerging materials, which may provide yet unseen wearing experiences. The authors suggest that progress in the field of genetic engineering will result in substantial advances in the properties and sustainability of natural materials. These processes will lead to a gradual replacement of non-sustainable products derived from petrochemicals.

Thanks to the emergence of synthetic biology and the ability to engineer organisms it is now possible to place the pigment biosynthesis pathways found in plant and animals into simpler microorganisms (like e coli, Streptomyces and yeast). Currently a number of companies are using DNA circuits to produce colourants in microorganisms (such as bacteria). These companies include PILI (France), Colorifix (UK), Ginkgo Bioworks (USA) and designers/consultants such as Natsai Audrey (UK). While such dyes produced in genetically modified organisms are non-toxic, the process is difficult to scale the colour "palette" is limited and requires substantial engineering to diversify.

The challenges involved in designing (with) such living materials include:

- Crafting the conditions of growth that lead to a desired outcome.
- Identifying and/or creating methods and tools that facilitate the monitoring and manipulation of such conditions, including computation (e.g. software and hardware to design material structures and properties, "CAD for biology") and manufacturing processes.

These challenges offer wide opportunities for designers to work closely to biologists, material scientists, and computer scientists, and also to the materials, in creating the capacity that responds to this demand. Designers can contribute to designing better computational and manufacturing tools and processes that will enable the integration of biological processes into conventional manufacturing.


Burberry Material Futures
Research Group
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+ PS (30 %) + MEK
+ MITILI (40 %)

Fig. 9 Credit: Sotiris Gonis

Biomimetic Textile Innovations

Scoping project author: Veronika Kapsali

Fig. 10 Speedo's Fastskin and Sharklet
Credit: Sotiris Gonis

Biomimetic is an approach to design that emerged from research seeking to apply knowledge and understanding from biophysics into engineering both to create models of biological mechanisms for further study and to fuel technological innovation. More recently, the impact of biomimetic principles and concepts have reached the wider science and humanities disciplines including architecture, urban planning and systems design. Researchers and designers are using biomimetic principles to develop design methods that use the inherent properties of materials – from fibre, yarn and structure, and in combination to programme material behaviour – and develop new understanding of the positive properties of bio-based materials for use within design.

The cases reviewed in the scoping report provide a snapshot of the key areas of development in the nascent space of biomimetic textile design; these include: optics, heat and moisture management, adhesion, mechanical properties, and active/programmable behaviours. The report demonstrates how properties and behaviours from biology can be translated using the systems, tools and processes of the textile industry and also highlights the plethora of opportunities emerging from textile technology as a platform for biomimicry.

Biomimicry of adhesion is a long-term quest, and which still presents opportunities to exceed in fastening and seam-free technologies. The best-known example is Velcro® (1961), which is based on the hook and loop textile system and is used widely as a fastening for garments and accessories. The GeckskinTM (2012) is an alternative way of creating gecko type adhesion by using combinations of stiff and elastic commodity materials such as Kevlar or Carbon fibre (stiff) with soft elastomers such as polyurethane or polydimethylsiloxane (PDMS). The adhesion is so high that it can be used for holding up heavy weights, and in industrial applications. Unsticking may also be desirable as a performance trait, which has been explored for example with the Sharklet Technologies and Speedo Fastskin, both decreasing drag action that help swimming performance in terms of speed; also the Lotus effect has also been explored as anti-adhesion feature that gives dirt repellent, self-cleaning properties to materials.

These and other examples show that application of biomimetic principles to material and textile design promises sustainable future materials and making processes that make optimal use of available resources and inform new practical circular approaches to manufacture such as low energy/ resource manufacture.

The main challenges and opportunities include:

- **Technology transfer:** there are conceptual and cultural barriers between biology and applied technological projects. There is ample space to facilitate building links with industry that will enable the flow of ideas, problems and solutions, and thus consolidating the link between consumer pull and technology push.

- **Development of suitable technology:** to realise and scale ideas from biology requires investment on technology and on integration with manufacturing processes. There is a real gap in pilot scale facilities for fibre and yarn design and development that would supply emerging textile designers with raw materials to work with, thus inhibit innovation in the UK within this space. However, this is also a huge opportunity for designers to partner with biologists in hacking currently available technology, as often small adjustments to existing technology is the most effective path.

- **New approaches to design:** Biology can provide ideas to inform the creative sector however, the framework for biomimetic innovation is focused on the functional aspect of materials and products and not on the aesthetic; designers of the future will be required to develop a deeper understanding of the mechanisms and processes that enable such additional functional properties in order to innovate in this space and develop new and meaningful approaches to design such as circular design, including practical strategies to design for reuse, refurbishment, remanufacture, and recycle.

Materials Circularity

Scoping project author: Thomas Leech

Fig.11 DIY Materials Corn Stalk
Credit: Sotiris Gonis

'Materials Circularity' is about producing useful materials that are not dependant on continued mining of our planet's finite resources. It embodies the idea that there is no 'away' so in order to ensure long-term sustainability we need to produce materials that meet the needs of the present without compromising the ability of future generations to meet their needs.

From all of the materials and case studies gathered in this material section of the scoping project, very few currently demonstrate true circularity as most fall into a category of 'cascading cycles' meaning materials are being developed as a reaction to waste – focusing on finding solutions downstream from a process rather than preventing waste in the first place. We are in a transitional phase where material innovators have a shared understanding for what circularity means and a clear vision of where we need to be, which is different from where we were 10 years ago.

Material innovators think that consumers should care about the provenance of the materials in the products they buy. This means that there is a push to create materials which are easier to identify and recycle. This it is proving to be an effective marketing strategy for the brands that use these materials. Many innovators are working at small scale and remain hidden from the global community. This means that lots of good work is going undiscovered. New materials are being developed but often just for the materials sake – and without a purpose driven application in mind.

Most of the materials found justify their sustainable or circular credentials by claiming to be biodegradable. However, there is less clarity over what biodegradability actually means and its definition seems to vary on a case by case basis. Biodegradable materials which end up in landfill have much less chance of being naturally cycled into useful biomass compared to materials which are collected and composted in closed loop systems where the methane released can also be captured in controlled conditions. more work could be done to unify what biodegradability means for each material. There is also no weighting system given to how fast a material takes to 'degrade'. We should be encouraging the development of materials which break down quickly.

Biological material development is cheaper, safer and more accessible than developing technological materials. An example is Piñatex® by Carmen Hijosa, founder of Ananas Anam Ltd. Piñatex® is a natural textile made from pineapple leaf fibre. The leaves used are the by-product of the fruit industry, which are traditionally discarded or burned. Adding value to this waste has created a new source of income for farming communities who otherwise rely on a seasonal harvest. Once the fibre has been stripped from the leaf the leftover biomass is retained to use as a natural fertiliser or biofuel, offering a further economic prospect. Ananas Anam currently work with farmers in the Philippines, and are looking for opportunities to work with other pineapple growing countries, supporting local economies and strengthening their exports. Another example is Aeropowder, a keratin-based material, produced by a start-up looking to use waste feathers from the poultry industry (thousands of tonnes are generated every day, and are treated as waste by-product) and to create new light weight and insulating materials for the construction and product industry. There is a particular opportunity to appropriate by-products and waste from the food industry to create alternative materials; examples included in the report utilised diverse sources, such as: crustaceans shells, citric fruit peels (Orange Fiber), coconut water (biocomposite Malai), sugar cane bagasse and straw (from agro-industrial waste), milk protein (Qmilk - commercially available milk-based biopolymer fibre that is produced from non-food secondary milk waste), potato peels (Chip[s] board), corn cobs and leaves, coffee ground beans, amongst others.

Technical material development is often absorbed by large corporations such as Unifi (Repreve Yarn) and Aquafil (Econyl - 'Adidas Parley') who simply have the resources and budgets to finance such material development. An example here is the project Ioncell lead by Prof. Herbert Sixta, part of the Trash2Cash project. Ioncell (Figure 4) is a technology that turns used textiles, pulp or even old newspapers into new textile fibres sustainably and without harmful chemicals. The process converts cellulose into fibres, which in turn can be made into long-lasting fabrics. The Ioncell process uses a novel solvent called ionic liquid. It's an environmentally friendly solvent that can be recycled and isn't flammable like many others.

The only chemicals applied are the non-toxic ionic liquid and water. They are both re-circulated in the process in a closed loop. Ioncell fibres feel soft and are strong even when wet. They're tenacious and work well in both clothing and technical applications. The Ioncell process could revolutionize the recycling of textile waste. It enables waste textiles to get a new life as high-quality fibres.

The challenges for scaling circular material research and development are numerous, and include:

- **Quality control.** Materials designed for circularity often struggle to meet the same strict quality and safety regulations, making it harder for manufacturers to choose circular materials over virgin materials.
- **Supply and demand.** Access to materials recovered from circular processes is limited by location, transportation cost, and how consistent the supply is.
- **Development costs.** It's difficult to raise money for experimental development.
- **Recovery Cost.** The expenses associated with collecting, sorting and separating waste materials means that there are insufficient financial incentives for waste produces to change their behaviour
- **Material categorisation.** Chemical engineers use different terminology than designers which makes it hard to link waste streams with opportunities. The absence of a central body means that there are lots of missed opportunities to connect problems with problem solvers.
- **Material prejudice.** But There is a difficulty in creating market pull for something previously defined as 'waste'.
- **People.** The people developing the materials have a different mindset to the entrepreneurs or businesses who can monetise them. It's difficult to form successful partnerships that will see a material to market.
- **Motivations.** Often conflicts arise between people wanting to make the materials open source vs protecting intellectual property.
- **Resale Value.** Most recycled materials can't command a high resale price.

As Ray Anderson founder of Interface famously put it "We believe the biggest threat to the world isn't climate change, it's attitude." In order to accelerate our transition to true material circularity we need to become better at connecting problems with problem solvers and celebrate and uncover much more of the small-scale work which is currently going on undiscovered.

Fig. 12 Malai Vegan Leather Credit: Sotiris Gonis

Smart Matter

Scoping project authors: Sara Robertson, Claire Miller, Dr. Charlene Smith, Sarah Taylor, and edited by Sara Robertson

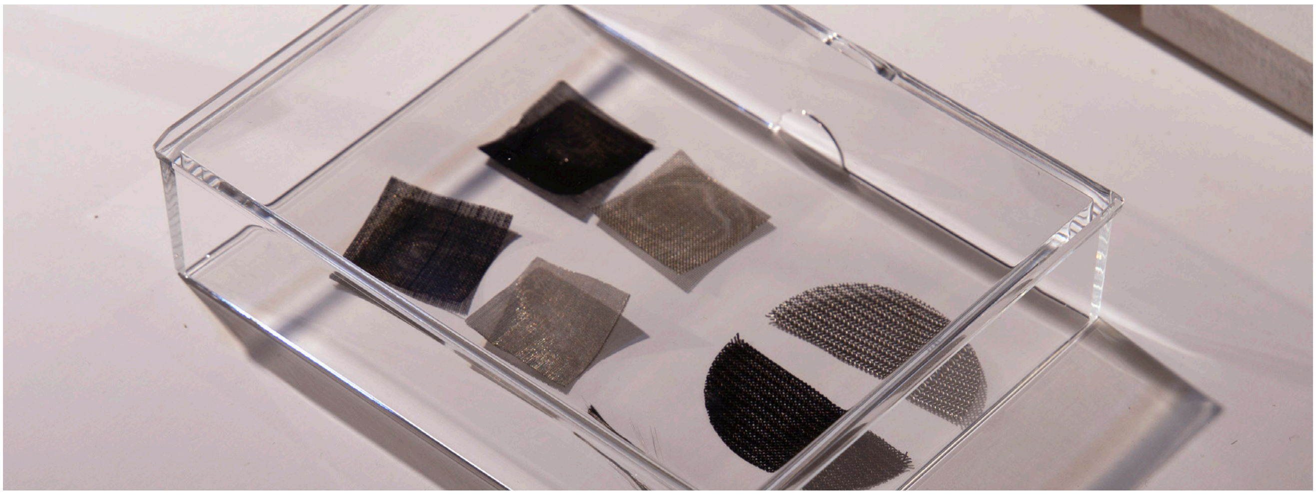

Fig. 13 Credit: Sotiris Gonis

Smart Matter deals with material developments that have relevance in sustainable and ethical textile development and design for a range of contexts. This includes, programmable material systems, multiscale materials and 2D materials and yarn based developments for smart textile structures or surfaces, and examples for use in e-textiles or wearables. Smart materials can imbue a surface with the ability to sense, respond and signal a change reversibly in its environment and/or offer a non-digital form of interactivity without the need for electronics or computational control.

Textiles can be smart without the use of electronics, and although we see a move towards integration of electronic functionality in some of the examples showcased here in the form of coatings, printing, nanoscale materials and in fibre form, it is possible to see a key trend of research moving towards bioinspired programmable materials or bio-based material development. Research and practice within e-textiles has new hybrid forms through approaches to material development combining electronic functionality with natural materials, textile waste, development of new tools, services and systems with an emphasis on more sustainable methods and practice, socially connected and open source e-textiles.

This can be seen in examples such as the 'smart-natural' programmable materials such as the work by Dr Jane Scott (2018), inspired by ideas of biomimicry that respond to atmospheric stimuli, and change shape as humidity increases and BioLogic by MIT and Microsoft Research that used natto bacteria cells as a coating that acted as a living nanoactuator, allowing the surface of the textile to change shape. Dr. Jane Scott (University of Leeds), presents programmable knitting (Figure 5) as a new class of textiles which respond to environmental stimuli and can be programmed to change in shape as humidity levels increase. Scott developed a method to create complex shape change by control the direction of the swelling of the yarns via the configuration of the knitted structure.

'BioLogic' an interdisciplinary project between MIT Tangible Media group, Microsoft Research, RCA, and New Balance. The project used Natto bacteria cells that were harvested in a lab and printed onto a textile using a micron resolution bio-printer to form a coating that acted as a living nano-actuator; the cells inherent properties include expansion and contraction in response to moisture levels, that allowed the surface of the textile to change shape. We see the engineered flaps within the textile open based on the increase in body temperature of the wearer, allowing sweat to evaporate and the body to cool down.

The same principle has been used in another MIT collaboration, but this time with Puma, where a Breathing Shoe was proposed. Here the biologically active trainer "pushes the boundaries of bio-fabrication and enables personalized ventilation by growing its own air passageways that keep the foot cool" [1] .

These examples, show us that smart matter is moving into a biological sphere, and challenging conventional understandings that smart materials for use in smart textiles incorporate electronics.

The main opportunities and challenges include:

- **Blending research and artisanship:** much of the work in this space requires a balance between systematic tinkering with materials, and intuition, that taken together enable novel material outcomes to emerge.
- **Multi-disciplinary and cross-sector teams:** working together to develop new products to sustain heritage textile manufacturers, transfer knowledge of new materials and utilize waste products for new contexts

1 PUMA and MIT Design Lab. Can Bacteria in Clothing really make an Athlete faster? Available at: <https://design.mit.edu/projects/puma-biodesign>

Sustainable Future Manufacturing

Scoping Experts: Susan Postlethwaite, Marie Holm, Arantza Vilas, Hannah Stewart, Graeme Raeburn, Pooya Sareh, and Sina Sareh

Fig.14 Design < > Research. 2018.
Credit: Sotiris Gonis

Advances in manufacturing technologies are leading the way to more flexible, customisable, distributed and localised forms of manufacturing. Complex mechanised and robotised, intelligent, automated and agile production processes for the manufacture of apparel, accessories and products are developing rapidly. Existing systems still generally propose a Linear Industrial Economy (LIE) model, in which competitiveness comes from higher economies of scale – bigger volumes enable lower unit costs – and process optimisation up to the point of sale, when ownership and liability for the cost of risk and waste are passed on to the buyer [2].

Challenging this model in an innovative way will fundamentally alter how designers engage with Industry 4.0, while addressing scaling, siting, resource availability and security, infrastructure, the future of work, and the re-education and reskilling of workforces. Additionally, transitioning towards circular approaches may mean larger manufacturers making equipment and technical support available to SMEs and micro-businesses in new models of engagement. With the emergence of the so-called digital artisan, this is already starting to happen.

The Circular Economy (CE) has not yet developed widely beyond theory, but as digital fabrication technologies enable the direct translation of data into objects [3], mass customisation and small-batch production become both economically and technically feasible. Designing with multiple materials within a single product makes disassembly and reuse more complex. Designing for a circular economy suggests innovating for end of life – designing in disassembly and separation of mixed fibres and materials, to enable product and/or material life extension. The Circular Economy model proposes that many new technologies and processes in chemical engineering and material science can be focused on reuse, repair and remanufacture, in the creation of 'framework conditions [that] will promote and reward the emergence of sustainable, ethical and competitive solutions'[4].

3D-knit technologies and 3D-woven spacer fabrics are rapidly developing fields, and their potential has been widely exploited, particularly in sportswear, but also in heavy industry. The additional functionality of these textiles, their heat-regulating abilities and cushioning properties are valuable in multiple fields, and there is currently renewed interest in 3D-woven shell production as new technology speeds up complex processes.

Computer Aided Design (CAD) systems assist in pre-determining configurations prior to production, and potentially give the consumer more autonomy over the resulting designs. Networked CAD systems, virtual sampling, completely roboticised production units, and on-demand and mass customisation possibilities mean large machine-engineering companies can make technical support and machine time available to different enterprises at different scales, from SMEs to medium-volume producers. CAD-linked systems promise quicker and cheaper sampling, more realistic online visualisation, less waste and less post-production finishing.

There has been innovation in other technologies that together pave the way for circular economic models, for example: microwave-dissolvable threads for ease of disassembly; laser-cutting, laser-distressing and finishing innovations that use fewer chemical processes and are therefore safer for operators and the environment; and seam-welding technologies, taped-seam systems and other seam-free developments for zero-waste production and ease of disassembly.

Sustainable Future Manufacturing in fashion means a switch to holistic design, production, and closed-loop processes; efficiency based on dynamic supply and local production (reshoring), utilizing lower impact raw materials such as managed-source cellulosic synthetics or perpetually recyclable polymers, combined with future craft techniques, and responsible end-of-life options are all essential elements.

2 Stahel, W.R., 2018. Circular Industrial Economy. In: Charter, M. ed., 2018. Designing for the Circular Economy. Routledge.

3 Brettel, M., Friederichsen, N., Keller, M. and Rosenberg, M., 2014. How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective. International Journal of Mechanical, Industrial Science and Engineering, 8 (1), pp.37-44.

4 Stahel, W.R., 2018.

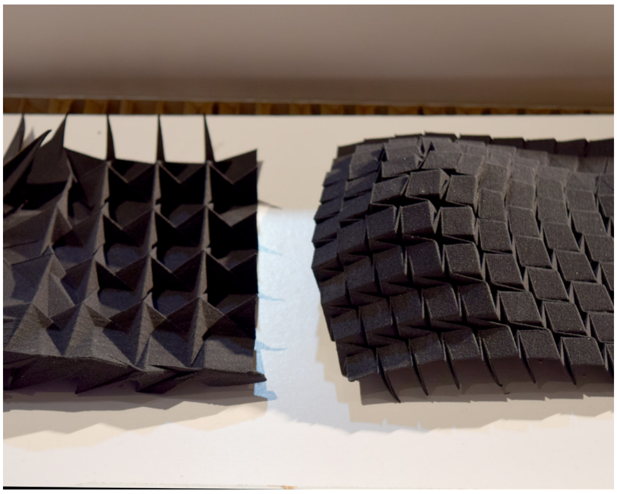

Fig. 15 Interfashionality Tsai-Chun Huang and Mingjing Lin. Credit: Anna Winter

Fig. 16 Marie Bach Holm 3D Printed Sample Credit: Anna Winter

Fig. 17 Weaving Sample by Amber Chen. Credit: Anna Winter

Fig. 18 Adidas Future Craft Shoe Credit: Anna Winter

Digital Craft: Pleating and Folding Processes and Technologies

Scoping project author: Arantza Vilas

Pleating and folding when understood as a design principle, enable the creation of structure, movement and volume within a fashion context. Those qualities extend even more when applied to the broader context of materials: a rigid one-plane material acquires mechanical qualities which enables it to expand and contract, change its size significantly, move and gain strength, amongst many others. Understood in this way, pleating and folding can help to find design solutions in potentially unexpected fields: from cancer treatment (PhD researcher from Harvard-MIT program in Health Sciences and Technology, Katerina Mantzavinou is developing origami inspired structures that deliver treatment to the abdomen of patients with ovarian cancer) to aerospace. From metamaterials (such as the case of Orimetric), which offer an array of solutions in one product; to develop transformable smart materials that follow folding principles and offer accessible, sustainable, and low-cost solutions that can be applied in both industrial and design practices.

Its strong associations with craft makes it familiar and we are drawn to interact with it no matter how complex an object may appear. Artisanal processes are still relevant and serve as an inspiration for innovative developments. In Europe big luxury brands are interested in preserving this knowledge and heritage, and other surviving companies have started offering internship programs to ensure the knowledge is disseminated (Atelier Lognon in France and Ciment Pleating in the UK). The disappearance of highly innovative companies in countries like Japan (such as Inoue Pleats) driven by the pressure of cheaper manufacturing outside the country has inspired (or forced) machine manufacturers to start offering pleating services (as is the case of Sankyo Pleats) taking it to a very high standard.

One-part processes are taking central stage by programming materials prior to construction. The substrates, print pastes and yarn choices are crucial: understanding the way the resulting outcome is going to fold requires selecting yarns that provide the flexibility as well as ones that retain the memory. Key to this is the combination of intelligent pattern-design engineering and an understanding of the craft. Flexible compounds and filaments are also enabling the creation of flexible pleated materials in one-part processes. A good example is Filaflex (TPE, thermoplastic elastomer), a printing filament manufactured in Spain, and one of the most flexible existing filaments in the market. It has been described as a challenging material to print with that enables a high level of detail.

Programming materials (digital software and fabrication methods) are changing the manufacturing landscape: the emerging field of Active Matter is demonstrating that existing materials can be programmed to respond to environmental stimuli and therefore adapt to changes in circumstances.

CAD systems assist to predetermine configurations prior to production and potentially give the consumer more autonomy over the resulting configurations. Hand craft and digital craft are becoming even more hybridised; current digital aesthetics have the opportunity to evolve and embrace the heritage of craft. Aran Azkarate from Comme de Machines said in conversation that "the future has a "retro" look", referring to an aesthetic which is not immediately associated with technology. The current digital aesthetics have the opportunity to evolve into something much more familiar and sensual that carries the heritage of craft. This is not led by nostalgia but a desire of connection and adaptability, belonging and authenticity.

Opportunities and challenges for digital craft pleating and folding processes include:

- Material developments are key to advances in manufacturing and fabrication of pleated and folded materials and opportunities are opening for advance, programmable and bio-based materials.

- Established textile processes and commercially available products can be exploited to generate new pleated outcomes.

- The technological developments in traditional textile processes such as print, weave and knit have changed the way in which materials can be pleated. Programming materials that respond to passive energy following pleating patterns -or even further, universal grids- with no complex electronic, hydraulic or pneumatic systems could mean a paradigm shift in the way we conceive materials and their full cycle (from product manufacturing, through distribution to disposal/ disassembly).

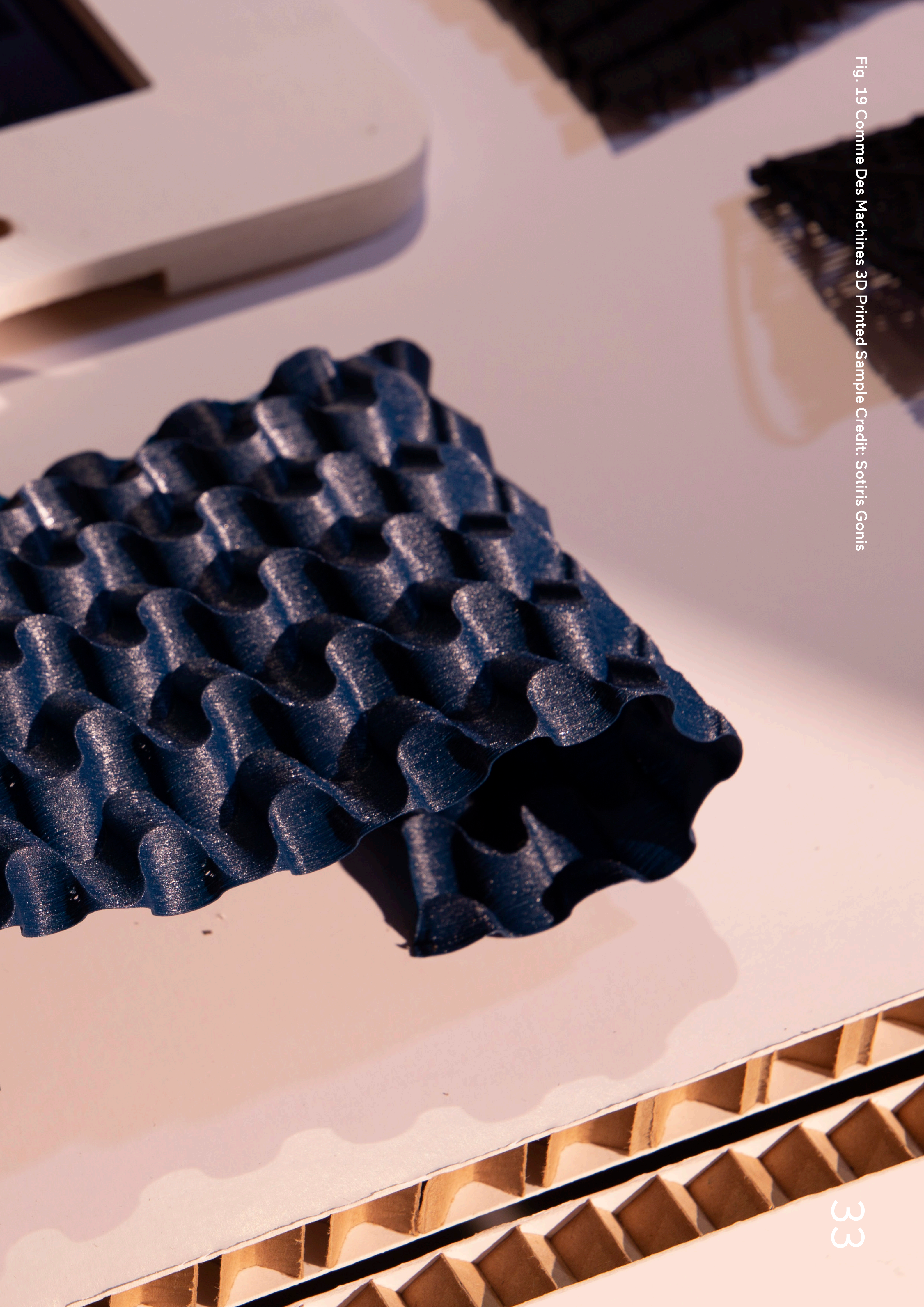

Fig. 19 Comme Des Machines 3D Printed Sample Credit: Sotiris Gonis

The Materiality of 3D Printing

Scoping project author: Marie Bach Holm

To enable the printing of fully functional textiles, we need to look at the materiality of 3D printing. So far, the most useable print material has been a silicone-like plastic, still quite far from the soft fibres that surround us every day. Combining soft materials and modified machinery with computer software, which efficiently allows the designer to create structures and surfaces on a fibre scale, is what is needed to expand the field of 3D printed textiles.

Diversity in materials, technology and knowledge is exactly what is needed to create functional and sustainable 3D printed textiles. To develop materials that consider both functionality, aesthetics and re-use, printing needs to go beyond stacking layers of plastic. Research that combines developments in non-woven textiles and 3D print technologies would provide a way forward. Merging existing production methods with 3D printing might be the first step towards creating a 3D printed textile that has the same handling qualities as traditional textiles. Marie Bach Holm's project 'Personal Plastics' (Figure 8) challenges the aesthetics and value of recycled plastics. She sought to apply the same knowledge and skill from working with textiles to plastic waste. Using dyeing, printmaking, embossing, spinning and other traditional textile techniques to transform the aesthetics of waste plastic.

Nike's Flyprint shoe is made using a digital fabrication process known as solid deposit modelling. Thermoplastic polyurethane filaments are melted in a programmed weave-like structure in an interpretation of a classic warp and weft woven. Nike has been able to produce at volume and reduce a 30-operation construction cycle down to 8 or 9 operations using this system.

Opportunities and Challenges in additive manufacture include:

- Developing new and advanced material structures must be done without compromising their sustainability.
- Looking at new material possibilities, we must also look at our current waste streams.
- Basing future material research on waste clothing, it will ensure that all textiles become part of a completely closed-loop production system.

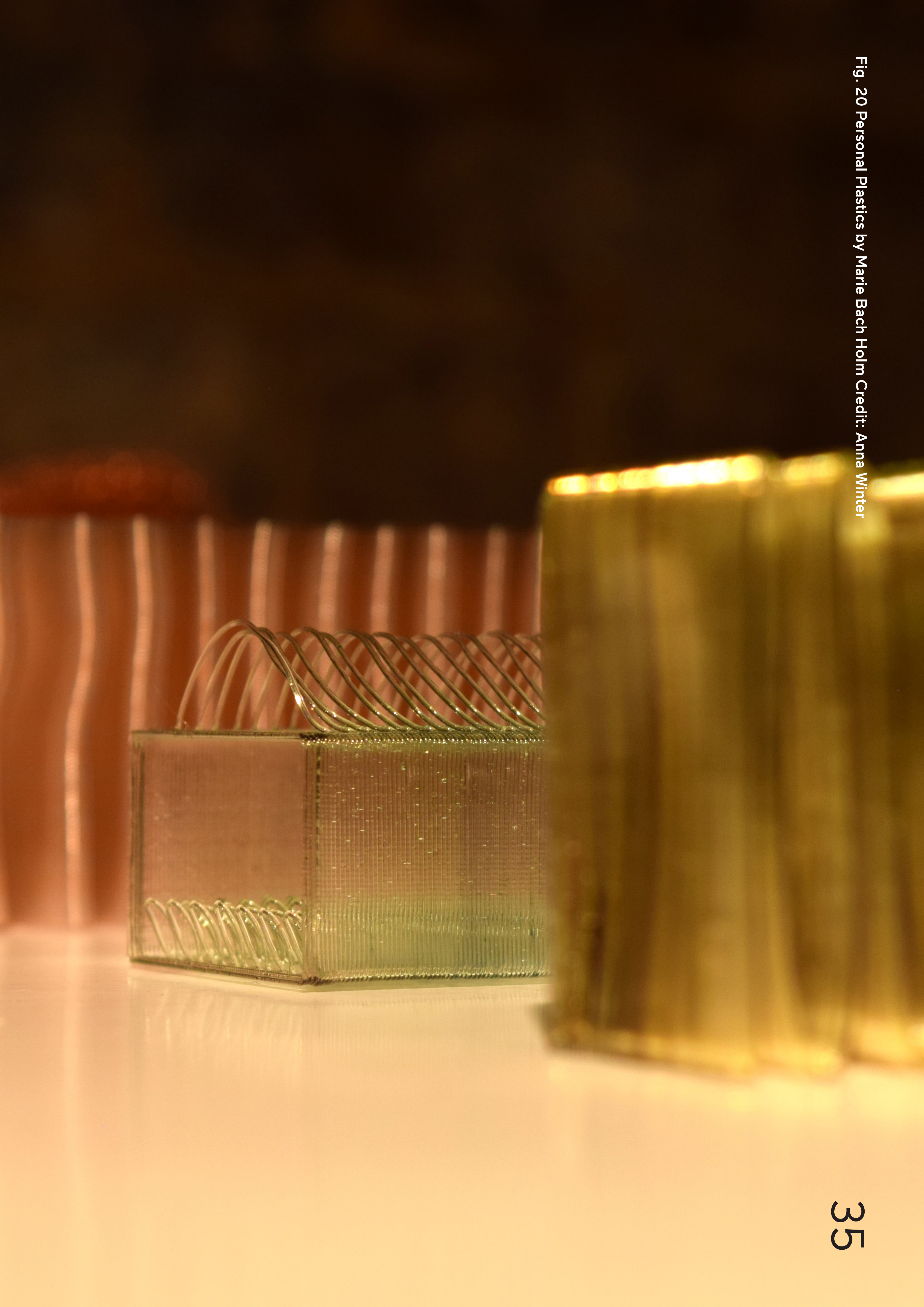

Fig. 20 Personal Plastics by Marie Bach Holm Credit: Anna Winter

3D Knitted, Woven and Advanced Manufacturing Technologies

Scoping project author: Susan Postlethwaite

3D knit technologies and 3D woven spacer fabrics are a rapidly developing field and are widely used in sportswear. These fabrication techniques are used for medical scaffolds, protective clothing and for in engineering and architecture. 3D knit's heat regulating, moisture wicking and cushioning properties are enhanced by its zero-waste production method. There is currently renewed interest in 3D woven shell production. Extensive use of multiple new technologies can often appear in a single artefact – trainers commonly have a 3D knitted or spacer fabric upper and 3D printed or moulded soles.

The Adidas Futurecraft 4D is a new low-top running shoe. It features sock-like construction, Primeknit, and an engineered sole created, as Adidas claim, with light and oxygen. Reebok has partnerships with entrepreneur, Joe Doucet; design studio, Odd Matter; and design company, Modlato, developing a collection of fitness accessory prototypes using its footwear technology, FlexWeave. This new weaving technology manipulates textiles into a 'figure-8 structure that can interlock a variety of different individual fibres', and is reportedly strong and light. Reebok has also partnered with Savile Row tailors Huntsman and Sons to use non-traditional materials in the FlexWeave process to create bespoke garments.

Shima's Apex System is claimed to improve workflow, save time, money and speed up the decision-making process. How this affects the quality of the design process, the work satisfaction, well-being or flourishing of designers once you remove or alter knowledge bases and manual handling of yarn and textile, or how this might be measured, has not apparently been a focus of research.

Apex is a CAD sampling virtual simulation system and can be used as a stand-alone design tool. It creates yarn simulations from its library of over 150 types to help designers understand how yarns effect designs at different gauges and stitch constructions where there are 1000 different options. Images and photographs can be automatically converted into stitches and colours can be chosen from a pre-existing library or scanned in. Apex has a patternmaking, sizing and making function for creating and editing patterns for knitted and woven apparel. The claim is that photorealistic simulations can be produced and as the technology develops so these simulations will become more sophisticated.

STOLL, Germany, and Myant, Inc., a Canadian textile computing company, have launched a Digital Textile Factory to provide the foundations for the mass application and adoption of Textile Computing, which they propose as a new industry category that merges advancements in engineering and material science. They claim to be providing textile-based solutions for companies wanting to innovate and connect textiles to the world of the Internet of Things. Global scale access through virtual networks will enable partners and customers to access Stoll's robotic 3D knit technology expertise, and Mayant's proprietary technology related to biometric sensing and actuation. It is proposed that Stoll/Mayant's Digital Textile Factory will give 'entrepreneurs, innovators and established industry partners' access to a virtual factory for ideation, research & development, rapid prototyping, and design and manufacturing at scale. This initiative is proposed to propagate and democratize advanced manufacturing techniques and access to the most advanced textile computing machinery in the world. Stoll/Mayant say that they are 'creating a platform for innovation and disruption across major industries including healthcare, transportation and wellbeing. A model where manufacturing is geographically distributed to satisfy local needs.'

In relation to seaming technology, there has been innovation in microwave dissolvable threads for ease of disassembly such as Wear2 Ecostitching Technology. Ultrasonic non-puncture seaming technologies, welding, bonding, and heat sealing provide other options to standard sewing methods. Zero waste pattern cutting developments led by designer/pattern cutters such as Timo Rissanen and Holy Mc Quillan, are leading to garments with fewer seams in designs, less waste in production, and promoting the use of sonic welding and taped seam technologies for ease of disassembly. However, seam free options have their restrictions over elasticity. Framis Italia, is well-known for its welding technology, "NoSo" that is based on bonding. The bonding tape is used together with hot-air welding. Framis has recently launched its latest portable machine, 'El Nino', for hot-air welding.

Bemis is the maker of Sewfree, one of the leading adhesive films being used to replace stitches. Products range from intimate apparel, lifestyle garments, technical outerwear, accessory items and footwear. Adhesive film is being used to bond fabrics and components, including everything from lace and meshes to ripstop nylons, all in one step, by such manufacturers in the outdoor industry as Arc'Teryx, Mountain Hardwear and Marmot.

Sew Systems Ltd., in Leicester produce ultrasonic, high-frequency, and taping machines for industry. Garments can be constructed using a combination of welding techniques, laser cutting, bonding and taping. A specialised sample room and bonding department has been developed where Sew Systems produce small and specialised runs for niche industries. Machines are developed with mass production in mind and are specifically engineered to do singular jobs. This technology does away with the need for glues and drying time. Bonded garment technology allows for a slimmer profile, and less abrasion for the end user are achieved with bonded seaming. A bonded seam can also initiate the stretch and recovery of the fabric better than stitching. Seams can be waterproof and will weigh less than a sewn garment. Bonding also eliminates or reduces the amount of thread used in any one garment. Volleback's Graphene Jacket makes full use of sealed seam technology. Pfaff, H&H, 2Hanfor, Vetron, Ardmel, Juki Corporation, Nucleus Ultrasonics, and Schips AG Automation, also produce machinery for bonding and welding.

The use of laser technology in the apparel industry has established solutions to manufacture using laser marking. The surface of fabric is distressed and laser engraved, where controlled cutting is set to a required depth. It has been used extensively as the replacement of some conventional dry processes like sand blasting, hand sanding, destroying, and grinding etc., which are harmful to the environment. Levi's F.L.X. technology is a laser-powered process that allows consumers to customise and personalise a unique distressed finish on their jeans. Levi's claim a change of manufacturing process to a digital transformation of the supply chain from end to end with a whole new operating model.

Opportunities and challenges in 3D woven, knit and advanced manufacturing technologies include:

- Rethinking current manufacturing techniques: fusion of advanced networked weaving technology, 3D circular knitting, and conductive spacer fabrics with additive manufacturing techniques.

- The ability to over-mould onto fabrics opens opportunities for integrated sensing.

- Advanced production methods: electrospinning, electro-spraying and multi-material 3D printing have the potential to be scaled.

- Transitioning towards circular approaches mean developing new business models by start-ups and SMEs that are more agile and not locked into existing systems. Reverse logistics systems/reverse supply networks to capture products.

- New training for an increasingly deskilled workforce is necessary.

Fig. 21 3D Weave Samples by Oluwaseyi Sosanya bottom) 3D knit shoe by Stoll (top) Credit: Sotiris Gonis

Localised Production and Dynamic Demand

Scoping project author: Graeme Raeburn

Fig. 22 Adidas Future Craft Shoe
Credit: Sotiris Gonis

The current production model in the Fashion and Textiles industry is unsustainable; the majority of the $300 trillion Apparel industry is a one-way, Take-Make-Dispose method. Radical shifts have to occur for the industry – and consumers - to align with the future carbon currency.

Currently financial incentives on both supplier side and high street/ consumer side are low. Switching from established, budget-driven streams with known profit and margins, risk the disruption of investing and exploring alternatives. However, change is being initiated on multiple levels, from visionary multi-nationals seeking to define and own the assets of future fashion, to a rediscovery of craft on local and individual basis.

With the ambition of providing low-financial cost to the consumer, a global supply chain is extremely inefficient in energy cost with its reliance on non-renewable materials, dependency on fossil-fuels, subtractive manufacturing methods, transport distances, stock warehousing and long-term turnover, low utilization and repair, with eventual landfill disposal. A huge amount of embedded energy is simply buried in a hole in the ground.

Sustainable future fashion means a switch to holistic design, production, and closed-loop processes. Efficiency based on dynamic supply and local production, utilizing lower impact raw materials such as managed-source cellulosic synthetics or perpetually recyclable polymers, combined with future craft techniques, and responsible end-of-life options are all essential elements. When designing for local ecosystems, issues of circularity should be highlighted for designer and consumers alike, in order that informed value choices can be made. Ultimately, does radically shifting consumer behaviour have to be led by an industry which is both paradoxically reliant on old, inefficient processes, but whose future relies on making this change or does their need to be legislation to enforce such action? The question is how to accelerate the shift, and what the catalysts are?

An example is Adidas Speedfactory that combines efficient future-craft techniques with a fully automated process to reduce time to market.

Able to service closer-to-customer trend and demand, the units utilise a limited range of raw materials and techniques, developed for speed, versatility, and creative opportunity. The Speedfactory has reduced time to market by up to a third of regular methods. Also, greatly reduces stock holding and wastage, whilst remaining highly nimble with potential for both design and ergonomic customisation. The combination of additive construction (engineered knit, 3D print, glueless bonding) with efficient finishing techniques, Adidas claim to be creating a highly desirable new aesthetic. The AM4 is the result of Adidas® investing in local-scale, future-craft and automated production. The ambition: desirable, customisable footwear on a local/regional level, aligned with dynamic demand, minimum waste, additive manufacture, and optimal efficiency. This process is defining how footwear and apparel will be produced and consumed in the near to mid future.

Challenges and opportunities include:

- Positives are that speed to market is greatly reduced: ability to respond to demand dynamically; possibility to improve/evolve product in-season; reduced stock holding; ability for customisation.

- Quick response for quality control issues: reduced shipping/transport results in lower costs and reduced CO2 emissions.

- Reduced CO2 footprint: no overseas flights for development and quality control.

- Opportunity for additional loyalty service; repairs/rejuvenation/return at end-of-life.

- Benefits local/national economy.

- Challenges are cost, often higher wages, with training and upskilling workforces: Smaller market, with higher risk if supply chain is disrupted; efficient, technical equipment might be prohibitively expensive; minimum quantities and supply of fibre/textiles can be limiting; worker exploitation and abuse can still occur.

Alternative Production Distributions

Scoping project author: Hannah Stewart

As a globally distributed industry, fashion and apparel is closely associated with offshoring and long complex supply chains, with international brands dependent upon multiple countries for their production. Forecast future challenges, such as an end to cheap shipping, supply chain disruption alongside changing consumer expectations of production pose a risk at an industry scale. Current fashion and textile production networks have been characterised as 'rigid, capitally constrained and geographically misaligned.'

Alternative approaches are emerging as to how production and its consequences are distributed. These approaches range from the hyper-local such as Fibershed and the their 'soil-to-soil' model, to the hyper-global such as the Fab City concept of 'design global, produce local'. Fibershed is an intentional redistribution of regional textile communities into micro-supply clusters. Through a reorganisation of the relationships between material and product producers they are developing alternative product ranges with an emphasis on regional economy and contributing to sense of place. While desirable, the Fibershed model and the aspiration of a '150 mile' wardrobe is only can only be validated as viable in a rural economy with a strong agricultural industry. Future work would need to experiment with the viability of this approach in a broader range of places, and with a broader range of products.

For fashion a more eco-systemic approach to both supply chain management (awareness and alignment with both upstream and downstream partners) and the designed product itself is needed, considering the externalities of the whole life of a product and its post-use impact. These approaches have necessitated the creation of services and platforms that map processing facilities, match-making between designers, brands and producers within localities alongside 3rd party services facilitating distributed manufacturing.

Future challenges and opportunities include:

- The resilience and scalability of these alternative distributions of manufacturing needs to be investigated at a product level, testing alternative approaches to designing products that can adapt to local variables.

- Establishing standardised metrics for how we evaluate the impact.

Digitally Reconfiguring Industry

Scoping project author: Hannah Stewart

Increased connectivity and the effective use of data promises to transform the value chain of textiles manufacturing. Cloud Manufacturing (CM) and Industrial Digitization Technologies (IDT) have the potential to 'digitally reconfigure industry', to enable a future landscape of textiles production that is responsive, low impact and resilient. CM imagines existing manufacturing facilities as a set of services that can be increasingly orchestrated via digital interfaces and protocols. By making the on-the-ground factories visible to a digital system, a software based service can intelligently direct the flow of production through a network of suppliers. Automated orchestration can respond to disruption such as labour shortages or shipping problems and ensure a more efficient use of available resources. The more recent term IDT refers to the specific technologies that enable CM and also other approaches to augment, replace or re-calibrate how and where things are made. IDT's include: technologies that directly affect what it is possible or viable to make, i.e., for mass-customised garments; technologies increasing the transparency of material and product supply chains; i.e., track-and-trace technologies, distributed ledgers; where and who can make products, i.e. through domestic scale machines and digital design tools; and the automation of decision making or design, i.e., AI and machine learning. IDTs vary in where they operate. Kniterate is an example of an IDT (industrial digitisation technology).

IDTs include:

- Technologies that directly affect what it is possible or viable to make i.e., for mass-customised garments.
- Technologies increasing the transparency of material and product supply chains; i.e., track-and-trace technologies, distributed ledgers.
- Where and who can make products, i.e., through domestic scale machines and digital design tools.
- The automation of decision making or design i.e., AI and machine learning.

Kniterate is an operation that depends upon the existing built infrastructure of a place, but enables a re-routing of the process of going from cleaned and carded and spun wool to a garment. It has a digital interface that can be used by both children and professional designers to produce garments hyper-locally. Kniterate is early stage, they have an applied research need around validating the variability of wool types that are usable, and a need for designers to design garments that can incorporate those local variables.

There are a number of complicating factors currently affecting the uptake and widespread dissemination, these include:

- The need to enable digitisation of legacy machines which can sometimes be 100s of years old.
- Long lead times and remote inflexible supply chains make it challenging to test and trial IDTs and cloud manufacturing without significant disruption.
- An emphasis on traditional skills plus the necessity to upskill and reskill existing workforces.

Robotics in Manufacture

Scoping project author: Pooya Sareh and Sina Sareh

Humans have been dreaming up intelligent robots to do the tasks they can do themselves for more than 500 years. Nowadays, Robots are becoming the co-workers of humans in many industries around the world; the textile industry is no exception.

Sewing technology in apparel factories has changed relatively little since sewing machines were invented in the 1800s. While others have attempted to automate particular steps of the process of sewing it is only now that technology is becoming capable of creating an entire garment autonomously.

Having observed the way human hands guide soft textiles under sewing feet SoftWear technology uses computer vision to watch and analyse fabric so the system can move the material while sewing. Human operators use micro and macro manipulations of the fabric with their fingers and hands and elbows and feet. SoftWear's robots attempt to replicate these functions.

SoftWear's technology aims to replace workers in very high-volume production for simple processes like T-shirt and jeans production, where they claim automation makes most sense. SoftWear argues that the technology could have a positive impact in countries with large garment manufacturing industries. Workers might shift into doing more artisanal work, at higher wages. If robots make it economical to manufacture more clothing in the U.S. or Europe, where regulations better protect both the environment and labour, low-wage countries might be forced to improve their own performance to compete. SoftWear says it has calculated that a robot can create between 50 and 100 jobs downstream. By producing closer to consumers, and by reducing material waste as it sews, the technology can also reduce brands' carbon footprints. Fashion for Good, an initiative to improve the sustainability of the fashion industry, calculated that the Sewbot can help cut emissions by around 10%, and is supporting SoftWear through a scaling programme. Amazon filed a patent in April 2017 for "stitch on demand" technology that would sew clothing after an order is placed.

Opportunities and challenges for robotics in manufacture include:

- A new generation of leaders and

change agents is needed within the apparel industry with a combined skill-set of designer-led innovation underpinned with technology and engineering excellence which currently does not exist.

- Traditionally isolated knowledge bases need to be fused through an industry-academic framework to enable the development of agile manufacturing systems, smart materials and fashion design innovations.

- Circular economy models for the production of apparel and product can move from speculation to realization. Equipped with new understanding of how advanced technologies can interface with the apparel and product industries and innovative tools/ knowledge will diffuse into the wider design community.

Sustainable Future Consumer Experience

Scoping Experts: Gaia Crippa, Douglas Atkinson, Kat Thiel, and Alexa Pollmann

Fig.23 Wear and Seek by Peut Porter (Right), Levi's Commuter x Google Jacquard (middle) SensoreeFleXo (Left) Credit: Sotiris Gonis

We live in a connected world filled with online communications and interactive experiences. Artificial Intelligence is blurring the gap between technology and humanity, interpreting our emotions and apparently offering empathic responses. The advancement of technology, however, has left people yearning for deeper human connections with the world around us.

Research and design tapping into the Material and Immaterial strives to offer experiences that include real tactile feedback, captivating olfactory and audio experiences, and even the illusion of tasting food. Compelling sensorial experiences have a tremendous impact on our lifestyles and are a means through which we can reconnect to a more natural dimension and help to rediscover satisfying, compelling lives. Besides, the senses have an extraordinary power to inform and provide satisfaction, and by diversifying the range of sensory channels, designers can likewise diversify their reach. Designers are challenged to consider different abilities and are searching for diverse ways to stimulate our senses, to offer new alternatives for our interactions with the world.

The diversity of possibilities to stimulate people has also increased with the rise of Smart Wearables, which are highly diverse and encompass many types of product which incorporate computational systems worn on the body. Sensing, reacting to data, and in some cases communicating. Besides 'on the body' technology, the general acceptance of ubiquitous computing is providing fertile ground for the emergence of New Product Cultures that affect the meaning and usage of products.

In all of these scenarios, a better blend between the physical and digital presence of materials and products is required to support the narratives and information that people can benefit from accessing. This is also relevant for human activities, since, with the rise of local production and distributed manufacture, an improved communication of material experience is crucial for effective global connections. Moreover, with New Cultures of Design and Production, the roles of producer and consumer continually converge; the consumer becomes 'co-producer' or 'prosumer' as s/he actively contributes to the making of and hence the value of the product. Different ways of engaging and interacting with people have become more and more versatile with the beginning of the 4th industrial revolution. Having further insight into the production, people are becoming increasingly conscious about their choices, and care about material and product provenance, and if they are manufactured following socially and environmentally sustainable development conduct. 'Prosumers' are interested in products with a purpose, which can add value to their and other people's lives. The design community fully embraces the need for a change and is offering all its knowledge to provide new material resources and innovatory manufacturing approaches to facilitate social innovation that can lead to personal growth (self-actualisation and transcendence).

New Product Cultures

52–55

Scoping project author: Kat Thiel

Fig. 24 Lveis Commuter Jacket.
Credit: Anna Winter

Mass Customization and On Demand Production

47–48

Scoping project author: Alexa Pollmann

Fig. 25 Adidas Resistance Runner Shoe. Credit: Anna Winter

Immersive Experiences

49–51

Scoping project author: Alexa Pollmann

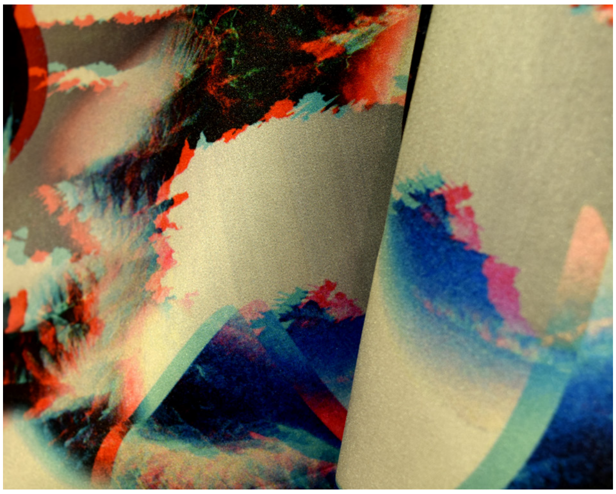

Fig. 26 Wear and Seek by Peut Porter
Credit: Anna Winter

Smart Wearables

52–53

Scoping project authors: Douglas Atkinson

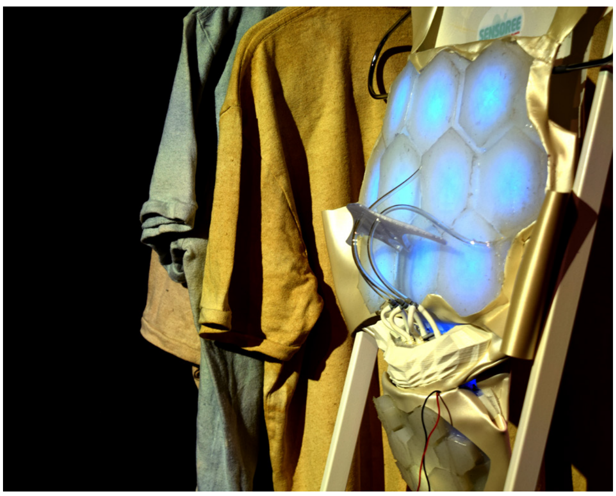

Fig. 27 SensoreeFleXo
Credit: Anna Winter

Material & Immaterial

Scoping project author: Gaia Crippa

54–56

Fig. 28 POLIMI DIY Materials.
Credit: Anna Winter

New Product Cultures

Scoping project author: Kat Thiel

The general acceptance of ubiquitous computing is providing fertile ground for the emergence of new product cultures that affect the meaning and usage of products. Consumers appreciate personalised experiences, unique products and limited edition runs and demand a quick and clear delivery of value through products and services – online and offline. US retailer Target has been running an exclusive app called Studio Connect since 2016, taking brand loyalty and trust building to new levels. Around 600 people are invited to be part of an online community, chosen for their influence and engagement rates. Members can give direct feedback to the design team's ideas and questions and so play an active part in the design process and gain rewards in exchange for their input [5] .

The shift to near Zero UI (User Interface) is heavily affecting and fuelling innovations in the fashion and textile sector. Fabrics and materials are turned into screens, aiming to help us use technologies more naturally and intune with human gestures, language and intuitive behaviour. Enhanced product experiences are seamless by design, providing purposefully unnoticeable or perceptible responses through the senses and movement. New functions and modes of usability for human-centric products are also tested in the context of environmental changes. Brick and mortar shops will transform into spaces that excite customers and function as a platform to inform, present and curate content and goods that align with the shopper's values. Augmented Reality apps will make it easier to try things at home before committing to purchases as seen by Timberland, Lacoste, Uniqlo, IKEA Place, Topshop and Anthropologie to name but a few.

Challenging current technology normal uptake, the project Wear & Seek by Peut-Porter, is an exemplar of an immersive interactive experience that uses enhanced vision systems to test and push the boundaries of their future role in design and social interaction.

HoloLenses and an AR app allow for a mixed reality experience that uses the various garments and patterns as triggers to create virtual landscapes and animations. The aim of the play is to send the visitors on a quest to understand the process of 'being watched' and 'being the one watching' in a world where our bodies are more than ever read and quantified with the help of machine vision.

Since the rise of social media, brands have worked with online influencers as brand ambassadors to connect with audiences' through their role models and need for authenticity and credibility. Going further, the expanding field of blockchain supported services will fill a gap in the transparency and provenance sector. Blockchain backed research and credibility certificates are beginning to emerge (Provenance, Lukso, My Bright Label) that track and reliably certify every step of the way of a product or service, giving customers a much-appreciated peace of mind as they put their money more and more where their values are.

Understanding how these advances can be scaled is crucial in identifying future user groups and will help interpret general improvements and implications that come with these innovations. Juggling the ethics of new technologies and materials and finding appropriate applications has been a constant challenge for the sector. Tommy Hilfiger might be the most prominent example of smart-tag use to date. In 2018, the company introduced bluetooth smart technology tags into a range of hoodies and trousers that track how often a garment is worn. The Tommy Jeans Xplore line rewards the customer with gift-cards, runway shows, concert tickets or limited editions for extensive use of their logo products. Wearing the garment is further gamified as customers can compete in challenges to earn more points[6]. The line has raised the question of data storage and ethical concerns in many media since its release but surely won't remain the only player in the game of brand loyalty strategies through tagging systems.

New products and services have traditionally been successful when they managed to address a mutual need or offered reliable convenience. Behaviour commonly changes with widespread social acceptance of a new product, service or value system. The implementation of technology and science in the fashion and textile sector have helped move the field into an exciting new territory that will continue to innovate.

Opportunities and challenges include:

- Quick, easy, borderless, inclusive experiences are the driving factors in product and service development. Convenience plays a huge role in whether users will take to like and continue to use a product or service or not. New products that are designed with a disregard of key societal tendencies and emotional needs are likely to fail the test of time. Product and service developers can learn a great deal from app culture and smartphones.

- **The civic:** Consumers and users insist on integrated sustainability, transparency and equality; the message is clear: substance over mere aesthetics. In such an ethical wave, pressing questions to the field are: How can fashion and aspiration be decoupled to make better contributions to markets and consumer experiences? What constitutes a satisfying fashion experience that does not necessarily involve the purchase of goods?

- **The technology:** We can see the push from big brands to align with tech to foster loyalty but this often comes with no regard for ethical use of gadgets, add-ons and physical computing that in itself faces massive challenges when it comes to material circularity. Can technology be used to create experiences that minimise the need to consume and add to the waste stream of products?

- **The functionality:** Good designers should be aware of their responsibility towards achievable sustainability and approach their designs by considering materials, manufacturing and the product experience in equal measures.

5 Wilson, M. 2018. Target has a secret app for superfans, and it looks like Instagram. Fast Company. Available at: <https://www.fastcompany.com/90177570/target-has-a-secret-app-for-superfans-and-it-lo oks-like-instagram>. Access on: 20 November 2018.

6 Available at: <https://www.dezeen.com/2018/07/30/tommy-hilfiger-xplore-smart-clothing-fashion/>. Access on: 20 November 2018.

Fig. 28 Wear and Seek by Peut Porter
Credit: Anna Winter

Mass Customization and On Demand Production

Scoping project author: Alexa Pollmann

The 4th Industrial Revolution offers a variety of new production methods. Two of its core assets are On-Demand Production and Mass Customisation. Both highly depend on user analysis and efficient logistics. The direct or indirect involvement of the end-user during the creation of goods and services takes centre-stage when developing successful models. The concomitant applications often rely on data-harvesting to further knowledge of the end-user and in turn bring about a new understanding of the products and values of companies.

In the now popular combination of online and offline market, Farfetch has developed a model for the shop of the future for which it collects data in the same manner as an online retailer in-shop and hopes to make physical shopping more intuitive. Upon entering, visitors to the physical shop can log in via a mobile phone app. The clothing rails will then record products the customer looks at – the selections can be edited by the user through swiping, resulting in less interaction between customer and store-staff. According to Mintel, 84% of customers wish for less interaction with store members. Equipment within store such as smart mirrors 'advise' shoppers on other items possibly suiting their taste and style using an algorithm unique to each customer.

The main benefits are less waste and reduced storage times, a closer customer relationship and a new definition of luxury. But the need for bespoke software and networked systems asks companies for big investments and the implementation of concomitant processes. The product-sector is often seen in danger of stripping design-processes down to modular outcomes. The marketing sector on the other hand needs to question its rights and ethical obligations in regards to privacy and information sharing.

To understand the transition from mass production to mass customization as 'a journey, not a destination'[7] is a recommendation that mirrors the complexity of setting up these new processes and reflects the major shift currently taking place in production and consumption – one that is culturally and economically important to analyse.

Opportunities and challenges include:

- **Over-Personalisation:** With Bentley, a high-end luxury car company has joined the new format of personalised and bespoke product selection. At Westfield shopping centre, (Stratford) an interactive screen uses emotional recognition technology: whilst watching an immersive film, the customer's facial expressions are read on engagement and a bespoke car is suggested in the end, making the choice of colour, wheels, leather and wood veneer for him.

- **'The Bubble':** Applications such as Face++, a Chinese face and body recognition app that is supposed to help improve customer experiences. Whilst it also offers safety in being employed as facial recognition software for AliPay (called "Smile to Pay"), it might soon be used for other services such as offerings in virtual mirrors or personalised ads when watching a shop window.

- **Merging of Online and Offline:** The 'Farfetch store of the future' shows a direction of retail that will evidently lead to customers having a certain expectation when entering a shop – one that includes an enhanced experience using technology. This is most likely going to

7 Fabrizio Salvador, Pablo Martin de Holan and Frank Piller, 'Cracking the code of Mass Customization', MIT Sloan Management Review, 2009; p 76

Immersive Experiences

Scoping project author: Alexa Pollmann

Today's immersive experiences market is presented with a width of possibilities, lately culminating in the idea of XR – Extended Reality. At the same time, the 'future economic Value of Immersive technologies and the challenge of integrating them with Artificial Intelligence and Machine Learning technologies has recently been identified as a potential high priority activity through various interactions with the research and business communities'[8].

The influence of this field reached every corner of the creative industries in 2016 and manifold practical applications in training, therapy, manufacturing, advertisement and retail have been found. The challenges of immersive experiences are twofold. The underlying technology still has plenty of optimisation to deliver and price-points are keeping the applications exclusive. On the other hand, the VR/AR community asks for the implementation of a moral code as there are little to no restrictions in legal and ethical matters.

With new head-mounted displays entering the market on a regular basis and the app and gaming industry behind it growing rapidly, the immersive experiences segment is here to stay and to revolutionise industries. The aspect of sustainability in this area is one that has rarely been looked at other than in the context of the 'empathy machine' – and could offer an important aspect and added value to the discussion around ethics, social norms and long-term benefits of enhanced experiences and virtual environments.

Applications are already widespread, but we see an easier diffusion with AR, due to the ease of just using a smartphone to engage with the additional digital layers. With Zara's new AR app launched mid 2018, one could wonder if the virtual mannequin is finally set to replace the real one and the experience offers a new take on the long talked about virtual fitting room. The merchandised products can be ordered immediately via the app or in the shop itself. Sharing the experience on social media is a big part of the campaign, suiting the brand with free publicity. Thus far, retail has offered a certain set of products in shop, but with help of AR, customers could easily be put into control and not only voice their wishes but check availability and compare products in store or on the high street. The fluid integration of physical and online experience is hence an integral part of retailers' challenge to keep up to date and relevant. ObsessAR, a one year old start-up, is currently being celebrated as the most promising AR platform for product selection and comparison empowering the customer.

There is also vast opportunity for educational experiences, given that 'Experiential Learning' described in Edgar Dale's 'Cone of Experiences'[9] claims the chance to remember things we enacted or actively participated in is much higher than if one reads or thinks about them. Here an example is the project Ghost Net, by BB studio (WEAR Sustain fund), which created an immersive experience to raise awareness about ocean pollution. This is an interactive VR scene produced from real data gathered by Imperial College, where the wearables were created considering sustainability (e.g. modular design for ease of repair and disassembly, organic fabrics).

The market size of AR & VR is expected to reach 215 billion US Dollars by 2021[10], but the issues with headsets still being quite heavy, wired or rather short lasting in regards to battery power will need to be overcome. If virtual assistants like Siri or Alexa become even better resolved, they could outsmart the need for a HMO for everyday tasks all-together. Unity Labs describe in their Mixed Reality Research Group the sense of Touch as being part of Mixed Reality, but even the idea of taste or smell have been explored in a set of projects. This year, FeelReal has presented a first - though clumsy - prototype of how haptics and smells could be added to VR through vibration motors, air fans, and a cartridge for eight smells.

Opportunities and challenges include:

- **Homemade Devices & DIY opportunities:** if the DIY community would be given funding and technological possibilities to dissect and reinvent the existing technologies, a long-term more accessible and democratic product – with the promise of understanding a sustainable future – might be the result.

- **VR / AR Ergonomics & Wear:** The current wear for VR & AR is led by an industrial design approach much less favourable and applicable in an everyday scenario. The role of the garment could easily be reset into a functional context, which has a lot of linkage to other fields of this research in regards to future materials and consumer experience.

- **Sensing & Perceiving:** The still clumsy approaches offered by the tech industry in relation to the many ways we sense and perceive in the various environments are nonetheless first steps into a direction which will become crucial in the long run. A collaboration with neuroscientists and psychologists in relation to smell, taste and sound of extended realities could offer an interesting alternative if given the main focus instead of being an addition to the overpowering visual features of AR & VR.

- **Ethical codex and cultural guidelines:** research is needed to analyse the

various dangers, hazards and challenges in collaboration with lawyers, medical doctors, anthropologists, philosophers and psychologists.
Sustainable Practice: It was surprising that throughout this scoping project, sustainability was a field barely or not looked at – apart from empathy ideas to educate users about critical socio-environmental situations. On the other hand, immersive experiences are using a lot of resources and energy.

- **Conversation with Contractors & Suppliers:** Companies such as Schott who develop high-tech glass solutions are possibly the unsung heroes of the current Mixed Reality hype, and looking at the key components to build the VR & AR headsets to understand the challenges and possibilities on such a level to more detail could be an interesting next step for research.

8 AHRC, Research and Partnership Development call for the Next Generation of Immersive Experiences, https://ahrc.ukri.org/documents/calls/immersive-call-guidance/

9 The cone of experience (2015) Virtual Reality and Augmented Reality is set to disrupt how we learn, teach and communicate. [retrieved 4 September 2018]. Available from: <http://immersivevreducation.com>.

10 Hackernoon (2018) VR vs AR: The Battle of Reality and Desires [retrieved 20 August 2018]. Available from: https://hackernoon.com/vr-vs-ar-the-battle-of-reality-and-desires-6d5034ff1eec

Smart Wearables

Scoping project author: Douglas Atkinson

The category of Smart Wearables is highly diverse and encompasses many types of product which incorporate computational systems worn on the body. Sensing, reacting to data and in some cases communicating. In the last decade smartwatches and fitness trackers have become commonplace and shifted social understandings of smart wearables towards solid accessory products. Many start-up businesses are now miniaturising the same movement and bio-sensing technologies to include them in other familiar items such as rings, necklaces and smart headphones, or 'hearables'. Cutting edge research often demonstrates a different approach, with interface sensors and functions defining the form of a device, rather than adding technology to recognisable products. This offers a potentially exciting space for designers to explore new categories of worn objects.

However smart wearables have historically been concerned with incorporating smart systems in garments, dating back to commercial examples from Phillips and Levis in the early 2000s. Smart clothing has slowly developed in parallel with innovations in new materials and electronics manufacturing techniques, but commercially available examples are still limited to sports and health tracking applications, or control of a smartphone. One example here is the Levi's Commuter Trucker Jacket that features conductive Jacquard™ thread woven into a touch-sensing panel on the cuff. The jacket links to your mobile device via Bluetooth® and, with a tap or brush of the cuff, you can control music, screen phone calls or get directions using a few simple gestures.

Health and wellbeing are significant social application areas for smart wearables and this is driving the development of experimental, flexible and stretchable electronics applied directly to the skin, including sensors and even displays. Moving, soft smart wearables are an emerging area of interest in relation to such developments and the burgeoning discipline of soft robotics, with prototypes exploring the replication of therapeutic touch and powered 'artificial muscles' to assist in movement.

Opportunities and challenges include:

- **Design for genuine user needs:** A key challenge which unites materials, manufacture and consumer experience research in smart wearables is the unchecked development of hardware based on novelty, rather than thorough scoping of user needs and in-depth studies of the social connotations of new device usage. A perspective from which to address the need/novelty divide is perhaps to explore the creation of devices based foremost on their function, rather than seeking familiar wearable items to fill with potentially needless technology.

- **Standardisation and interoperability:** a crucial role of standardisation will be to ensure interoperability, both between different smart wearables devices and between smart wearables and other smart objects and data sources. This may be a factor in the relatively slow development of smart wearables in comparison to other technology products. Wearable items are seen as a key part of IoT ecosystems, yet ensuring that they communicate with other devices has been a comparatively recent development.

- **Design for multiple functions and upgrades:** one approach to the problem of interoperability is to develop smart wearables as hardware platforms and rather than giving them specific functions, allow them to run varied programmes or Apps.

- **Rent, don't buy:** a business model which should be subject to further research is the rental of smart wearables. This prevents devices which are no longer used from going to waste, as they can be re-distributed to new users. An approach that may help reduce the effects of the high abandonment rates of smart wearables devices.

- **Explore sustainable material alternatives and designing for circularity:** the use of materials with less environmental impact is largely unexplored in smart wearables. Research into intersections between the Slow Fashion movement, garment mending and repair schemes and smart wearables could help to start dialogues around longer usage and slower development of these two traditionally fast paced product categories.

- **Promote trust and community:** devices to create real life, in-situ connections may help to ameliorate the effects of increasingly solitary lifestyles in post-industrial economies.

Fig. 29 FleXo Sensoree (Right) Unseen Explorer (Left)
Credit: Sotiris Gonis

Scoping project author: Gaia Crippa

Sensory Experience

The human need for touch and physical connections is dominant in a world where the cold surface of tablets, smartphones and laptops seem to drive our personal communications. The desire to turn tech more human and offer more emotionally fulfilling and comforting interactions are pushing researchers, scientists and designers to go beyond visual and sound effects and develop systems that provide compelling sensorial experiences even in the digital world. In the design arena, there are immense opportunities when it comes to heightening people's awareness of materials and processes; one example is in the simple act of shopping online, where the inability to touch fabrics frustrates consumers, who are used to evaluating physical textiles. iShoogle[11] is a fabric simulator that minimised this perceptual gap, enabling an accurate perception of the qualities of fabrics presented digitally.

The system reproduces the behaviour of the textile when it is creased, touched or stretched deepening on its properties. The accuracy of the reproduction gives the customers the illusion of touching it, providing an immediate understanding of the characteristics of the material. This system opens up incredible new opportunities for the fashion world in the digital era.

While online communications and digital systems require us to be always connected, people feel the need to slow down and re-appropriate a human dimension. Lingering on experiences and thoroughly enjoy the moment is becoming more significant for people and this affects the way we perceive the world around us, which is less material-oriented and more intangible, shifting our priorities from owing to experiencing. Through the powerful connection that exists between our senses and the emotions that we experience, it is possible to enhance well-being through fulfilling sensorial experiences. Fragrances and aromas, immersive colours, comforting tactile experiences and mood-altering sounds have been explored to create products. Designing for all the sensorial modalities help to create intimate, powerful customers experiences where customers are not just passively looking, but physically engaged and emotionally awake. We see the emergence of blended physical-digital experiences, such as:

Project Nourished is a Gastronomical VR and AR experience where different devices such as a headset, an aroma diffuser, a bone conduction transducer, 3D printed tableware and 3D printed objects that mimic the same texture and consistency of food are used all together to create an entirely virtual gustatory experience.

Love Project initiative by Guto Requena studio and D3 developed the Aura project to ask “What if you could touch your love story?” They have developed and deployed an App through which people can capture their emotions while telling their love story through their heart rate and voice oscillation; this data is used as input to develop a mandala-like design that is 3D printed and crafted into a 18k gold pendant.

Consciousness

People are becoming increasingly conscious about their choices and look for socio-environmental sustainability to be a standard. Customers want to act, and by embracing different eco-conscious practice, they fulfil the need for participation to the greatest good. The design community fully embraces the need for a change and is offering its knowledge to facilitate social innovation and circular approaches, such as:

Social consciousness: Social Label is an organisation that brings together the design communities with people with disabilities to create socio-economic opportunities for people with a distance to the labour market.

Repair and second hand: Patagonia Worn Wear programme allows to buy second-hand Patagonia clothes and packs or repair them through its website. This initiative celebrates the clothes we have and the stories they hold, extending the life of our belongings through repair, or, when necessary, recycling them into something new.

Recycling: Intimissimi Italian underwear brand teamed up with I:CO to give new life to unwanted knitwear, pyjamas or underwear by reusing materials to create new products. To promote this, they offer a voucher of 10£ for every five unwanted items from any brand.

Sharing economy: Wear the Walk is a service for renting clothes for up to 7 days from luxury independent labels paying a monthly subscription or simply per use.

Self-actualization

People are more open to material alternatives, and designers are experimenting with almost everything with the aim to identify socially sustainable new resources, from synthetic waste (plastic from the ocean), biological waste (hair and urine) to fast renewable natural resources (algae) and farming by-products (pineapple leaves and pine needles). Best of all, large companies and manufacturers including Adidas, Dell, H&M and global materials manufacturers have started following the path paved by designers. Examples include:

Crop-A-Porter, makes fabric out of crop waste such as banana and pineapple by-products. The new process, which extracts cellulose from the waste to create new fibre and textile, turns the waste into a new source.

Algae Plastic Designers Klarenbeek and Dros have envisioned a future where consumers can produce their own materials sourced locally and 3D print them to create new products. They have shortlisted a range of widely available ingredients like mycelium, potato starch, cocoa bean shells, and algae that can be dried and powdered to be incorporated in a blend with another biopolymer used as a binder, and natural additives. The mix is processed in a filament for 3D printing with an extruder that can be used to make new products.

DIY-Materials – The initiative promotes a new approach to sustainability where people can create their own materials at home using an abundant local resource from domestic waste such as cats fur, fruits skin or mussels shell to industrial discards such as fibreglass from boat hulls. One of the further developments of the project is to create an open-source platform where designers share the recipes for the production of their DIY materials to help everyone to produce their own resources at home.

11 Orzechowski, P.M., Padilla, S., Atkinson, D., Chantler, M.J., Baurley, S., Bianchi-Berthouze, N., Watkins, P. and Petreca, B., 2012. Archiving and simulation of fabrics with multi-gesture interfaces. In Proceedings of HCI.

Fig. 30 Design <> Research. Exhibition of scoping project outcomes during the London Design Festival 2018. Village Hall, Battersea Power Station.
Credit: Sotiris Gonis