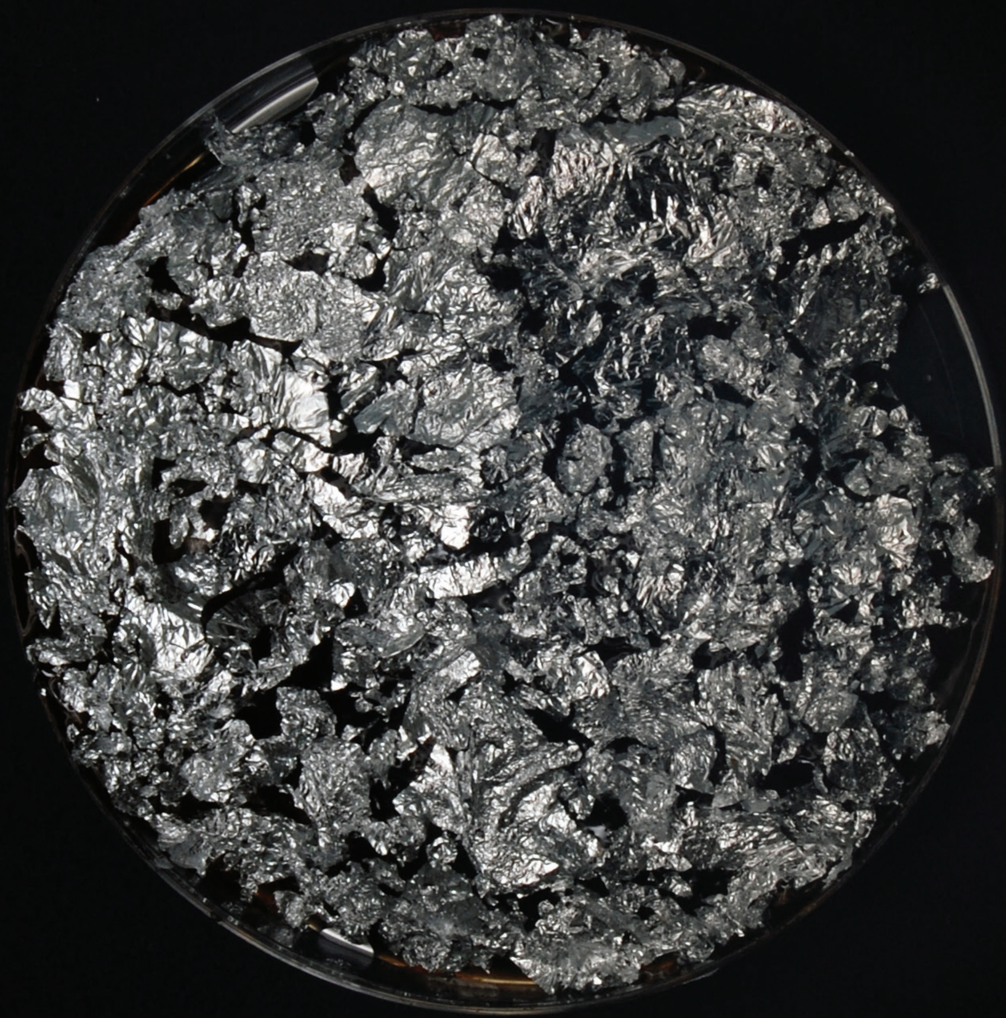
# BIOmatters

By Hannah Hansell



**A New Age of Biosynthetic-Technology in the Textile and Apparel Industry.**

**Masters Project**
*MA Sustainable Design*
*University of Brighton*

**Abstract**

**Cover Image:** Biofoiling Sample 2016, Hannah Hansell

# Abstract

This thesis explores how the role of design could change in the textile and apparel industry if synthetic biology is established as a new technology and production method. The field of synthetic biology is an industry developing methods for ‘reprogramming’ cells to produce bespoke materials, medicines and biofuels. The research explores this emerging industry from the perspective of fashion and textile industry application in order to seek sustainable solutions, new materials and circular models, to tackle key industry issues. It explores whether reprogrammed microbes could become our ‘factories of the future’ (Lee, 2005) fostering a new design paradigm based on cultivation, growth and living cells.

The overarching research aim is to explore whether critical/speculative design approaches can be utilised to research and question the potential of biosynthetic technologies in the textile and apparel industry. It draws upon theory and examples from the disciplines including bio art and design, design theory, future and sustainable fashion and textiles, biotechnology, synthetic biology and bioengineering in relation to new materials. To achieve this creative practice was utilized as the main research method. Focus groups and interviews will be conducted as a second phase of data collection during the exhibition of the work.

The research demonstrates that a new paradigm of production is emerging driven by designers, artists, start-ups and hackspaces. In this new paradigm of production, it is evident that a new paradigm of design needs to emerge. Critical/Speculative Design can play a key role in developing different narrative for discussion and analysis. In order to do this effectively it needs to be research driven and critical and less speculative and hypothetical. It also needs to engage in critical analysis and reflection through applying relevant research methods, analysis and dissemination.

Results are relevant too design researchers, textile designers, speculative designers and synthetic biologists working on collaborative design projects. Limitations of the study were predominately secondary research sources, limited opportunities for feedback and a lack of connection to synthetic biologists and potential to collaboration. Further research opportunities include engaging focus groups and interviewee’s with the objects and gaining primary qualitative data from these pieces. Exhibiting the work in various settings for further feedback and data collection. Further development of works from the scenario developed within this thesis addressing interconnecting topics and themes.

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Thank
you

# Acknowledgments

Thank you firstly to my tutors Tom Ainsworth and Gabriel Wulff for all of your time, feedback and support. You have helped me to restore faith in my abilities and develop a focused practice. To my fellow MASDers thank you for all of your advice, sessions in the pub and pep talks. Thank you to my husband Jack Hansell for not divorcing me, especially when I was working 7-day weeks. To my workplace UCA for funding part of my study, to my boss Gary Clough and Head of School Mike Addison for being supportive of me taking the time to study and funding me to go to conferences. To Scott Keiller for pushing me to write a paper and present at a conference and being so supportive of my research. To Richard Jones for all the coffee's and access to the workshops and Tomasz John for the lunchtime counselling. To my friends and family especially Kate Mead and Katherine Stewart for all the coaching and pub sessions, without you all, I wouldn't have made it to the end…

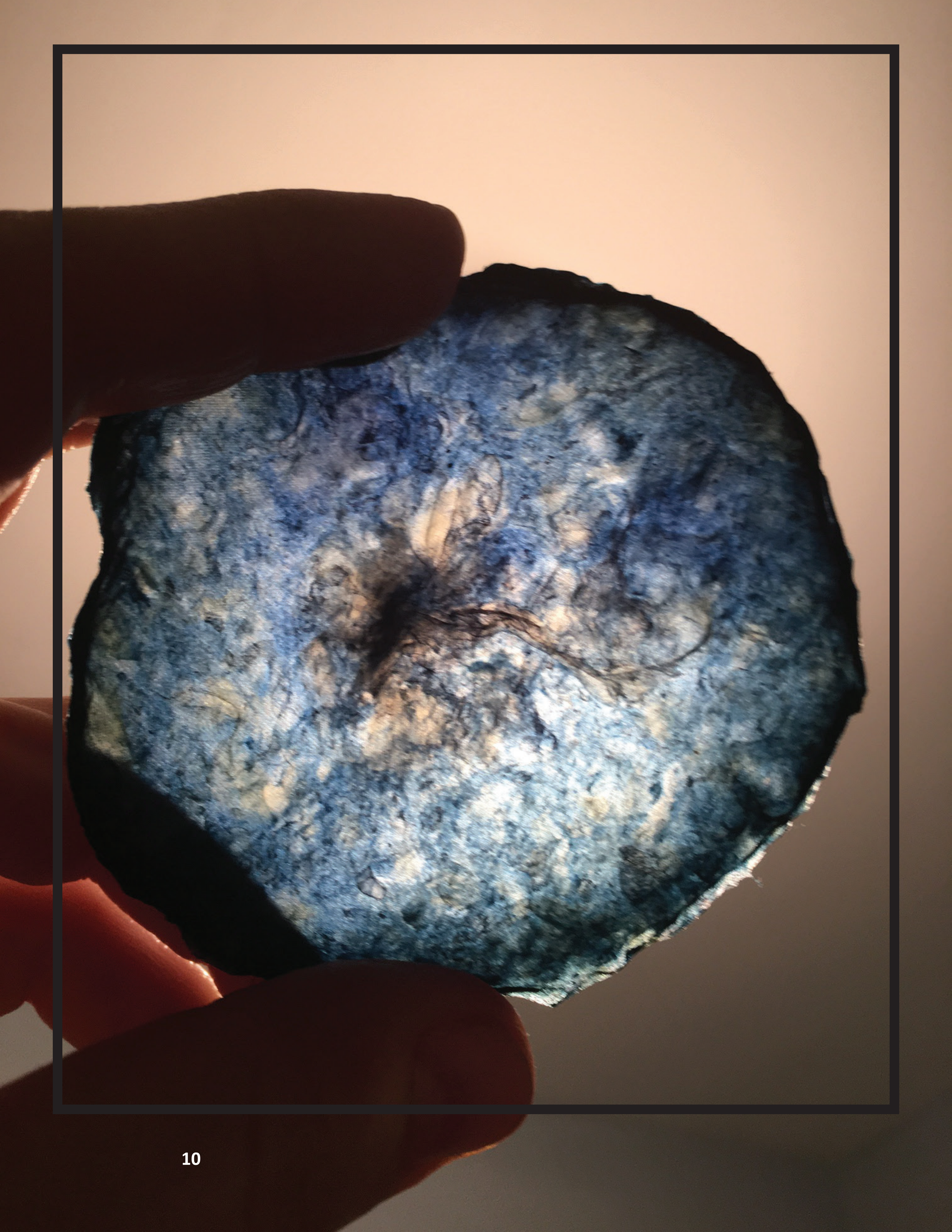
# My Background

I am a multidisciplinary designer and lecturer based in London. Working at UCA since 2012, I'm currently the Pathway Subject Leader for the International Pathway Programmes, managing and co-ordinating the International Foundation in Art, Design and Media and Graduate Diploma in Art and Design. My BA was in Contemporary Textile Practices at Norwich School of Art and Design (now NUA) and MFA Fine Art Textiles at Goldsmiths University. Following on from my MFA I worked with a range of small to medium size businesses, design companies, artists, crafts organisations and arts consultants.

Past exhibitions and residencies include, 'Eye of the Storm', Solo show at Tenderpixel, London, 2011, 2-year residency and exhibition 'M.I.D.A.I.R' at Middlesex University, 2011, 'Cupboard Love', Greenwich foot tunnel, Greenwich, London site specific drawing 2008, '10,10,10', Group Show, Tenderpixel Gallery, London – wall drawing 2008, 'Off The Wall' in conjunction with the London Literature festival, Queen Elizabeth Hall, Southbank Centre, London. Collaboration with EAR Maxwell Golden - performance drawing in foyer space, 2008, 'Lines of Grey', E-raum, Cologne, Germany – mural drawing, 2008, Tenderpixel, London (Listed in the London Design Festival) - mural drawing, 2008.

The decision to undertake a second MA in Sustainable Design at the University of Brighton was to support a refocus of my practice and research in order to apply for Doctorate study. My practice focuses on exploring and speculating what effect biotechnology will have on the fashion and textile industry in the future. I am particularly interested in this area in relation to future production and manufacture and the possibilities and tensions of biological textiles becoming part of consumer consumption within specific markets of the industry.

**Fig 1:** Bacterial Cellulose
Sample (2017)



# 01: Introduction

## What is My Focus?

> *"The nineteenth century was shaped by the mechanization of the industrial revolution; in the twentieth century, the silicon circuitry of an information revolution restructured modern life. Now some predict biotechnology will be the foremost driver of change for the twenty first century and synthetic biologists believe that their work will be integral to the success of this envisioned 'Biotechnology Revolution' through the international design (or redesign) of biology." (Ginsberg, 2014)*

Some believe that we are moving into a new industrial age, entering a fourth industrial revolution (Schwab, 2017) and that 3rd generation biotechnology could be a large part of this industry. Some predict that this new generation of biotechnology will be a key driver for change in the 21st Century. The World Economic Forum reported Systems Metabolic Engineering (a process of turning microbes into factories to produce chemical based materials) as one of the 'Top 10 Emerging Technologies of 2016'. Already creating biofuels, new manufacturing techniques, novel drugs and materials and medical technologies, synthetic biology; a form of biotechnology, offers the opportunity for living cells to become both the machine and the operating system (Ginsberg, 2014). This 'living technology' is being marketed as having the potential to tackle major global issues for energy, healthcare, the environment and material development by delivering new applications and improving existing industrial processes (UK Synthetic Biology Roadmap Coordination Group, 2012).

Alongside this a new material age and production paradigm focused on cultivation and growth is emerging. A growing industry of biotech startups, biohacker groups, research-led design studios, artists and synthetic biology accelerators working with organisms such as bacteria, yeast, fungi, algae and mammalian cells, using processes of cultivation, fermentation and engineering are creating materials with new aesthetics and properties and potentially more sustainable forms of existing products. This developing industry uses the practices and systems of biotechnology, biodesign and biofabrication to create materials, products and production systems from living cells. It is imagining a future where products and materials are designed and grown by biological organisms.

> *"Computers can now read and write with DNA. We can all access the profile of our personal genome and microbiomes. At the intersection of design, science, urban agriculture, brewing, cooking, 3d printing, making, even gardening, living cells are the becoming the factories of the future. From the most ancient methods of culturing products to the latest techniques in synthetic biology, we're starting to reimagine our surrounding world through a biological lens. (Lee, 2015)"*

As a textile practitioner my interest in this new material age and biotechnologies has stemmed from a desire to find sustainable solutions, new materials and circular economy models to tackle key industry issues. I am particularly interested in the potential of reprogrammed microbes becoming ‘factories of the future’ (Lee, 2005), what it will mean if we begin to ‘biofacture’ (Collet, 2017) materials and apparel. And what the shift from hand-made and man-made to ‘grow-made’ as suggested by Professor Carole Collet will mean for design practice within my industry.

## Why This Area?

Driven by new thinking for sustainable solutions many pioneers at the forefront of this new material age and developing technology are powered by the realisation that we only have one planet and that we need to work quickly at repairing the damage we have done to the micro biome. It is currently estimated that the global population is using 50% more planetary resources than is available (Moore and Rees, 2013). Key resources such as oil, a main raw material of the textile and apparel industry, are running out; fresh water resources are stretched and agriculture is beginning to suffer the effects of climate change (Ackerman and Stanton, 2013). With predictions that we will reach a global population of 9.6 billion people by 2050, we have a growing population that need to clothe, shelter and feed themselves (United Nations, 2013). Alongside this some believe that we have entered a new epoch and geological phase, the Anthropocene, an anthropogenic (human influenced) change to the earth, literally adding a new geological layer to the earth of man-made materials. We are making, consuming and disposing at an increasing rate, products that will outlive us, but often remain in our care for less than a year. The speed and scale of this linear use of resources is unparalleled and causing the textile industry (amongst others) to be stuck in an outdated model that promotes consumption and linear systems over longevity and circularity.

Throughout history fashion and textiles have embraced and celebrated change, action and diversity, presenting themselves as resilient systems. But many values and principles of these industries especially from cultural and social traditions seem to be being lost in the face of mass production, consumer demand and brand power. Values such as community, participation, exchange and resilience. There is a current need to go beyond (whilst still celebrating) the traditional ideas and expectations of design, production and manufacturing in the fashion and textile industries in order to consider new ways in which we can build long lasting quality and values. It is time for the textile industry to become a pioneer once again and reshape the way it does business (Dutch Awearness, 2016). To reduce its ecological impact whilst meeting the demands of a growing population on a finite planet. Could a new material age and phase of biotechnology be the answer to drive change, diversity and resilience once more?

If we can programme biology to make materials, there is potential to take control of the entire lifecycle (Ginsberg, 2014). For industry, synthetic biology could offer the opportunity to develop models that integrate material, energy, manufacturing, assembly and disposal. Waste could be biodegradable or remanufactured for the next set of products as closed material loops advocated by the Circular Economy (CE) (Ellen MacArthur Foundation, 2013). Opportunities for new resource streams and materials, design practice and education, markets and services could also emerge. But alongside this challenges in the form of ethics, regulations, green glossing and moral questions arise. There is much rhetoric around designable biology as a world changing and world saving sustainable technology, but there are also a number of questions that surround its claims and ambition that need to be answered (Ginsberg, 2014).

Biotech is a fast moving industry that needs to be questioned and scrutinized, design can play a key role here. In turn this suggests a further need to review how this would fit into design practice if we were going to start working with life as raw material, machine and operating system.

Such a new technology brings the potential for a radical shift of what fashion could be and do. Fashion is a form of protection, projection of identity, status and power. If materials ‘come to life’ in a sense or can perform certain actions such as clean themselves or the air around us, how will this change the functions, our relationship too and understanding of fashion and apparel? And can and should the challenges of the fashion industry be addressed through biotech?

## How am I Approaching This?

Designers and artists exploring the opportunities and challenges of this developing technology are often using a certain form of design that affords methods of future scoping and debate. Critical design has become an established area of design developed from radical design of the 1970’s and promoted by Dunne and Raby during their time at the Royal College of the Arts, London. Critical Design, sometimes termed Design for Debate and Speculative Design utilizes future scoping methods and speculative design scenario’s. Dunne and Raby state,

> *“Critical Design uses speculative design proposals to challenge narrow assumptions, preconceptions and givens about the role products play in everyday life. It is more of an attitude than anything else, a position rather than a method.” (Dunne & Raby,…)*

Although Dunne and Raby state that this is not a design method, in many senses it has become this. Artists and designers working with this form of design are presenting pertinent questions. But some feel that this form of design is simply a method of communication, too fictional in ideas and not starting realistic, feasible debates about the complexities of such emerging technology. Artists such as Oron Catt’s and Iona Zurr have developed a different form of design that they feel addresses the concerns of designing life more effectively, that of contestable design.

Alongside these areas of design there has also been an emergence of Biodesign, DIYbio, biohacking and makerspace communities. Design takes different forms within these areas bringing art and design practice together, collaborations between creatives and scientists, amateur makers and start-up companies. I will also review these spaces to investigate what forms of design are emerging here in order to critique their current roles and to establish if critical design could move to become a more research-driven form of design or if a new form of design practice needs to emerge.

The aim of this project is to explore what the role of design could and should be in the advancing biotechnology - synthetic biology, if established as a new technology, production method and part of design practice in the textile and apparel industry. It will explore whether critical/speculative design often used to debate this advancing technology can take more of a research driven role and if so what this might look like and involve. The project will begin by reviewing the relevant literature, projects, companies and industry reports to focus the study. It will then use this initial research to highlight emerging trends, form a future scenario and then shape a series of speculative objects through the research method of creative practice.

## Theoretical Location of the Study

This project will bring together theoretical elements from design, developing technologies within the biological sciences and fashion. It aims to critique and present the most relevant discussions on design and synthetic biology, critical, speculative, contestable and biological design, environmental, social, political and economic factors of the textile and apparel industry and emerging industry of synthetic biology and artists and designers practice working in the field of bio, speculative and contestable design. Its focus is upon addressing aims around the varying perspectives of what role design could and should play in the development of such biotechnology by questioning whether bio-artists and designers presenting speculative practice based work are engaging in research-based practice or whether there is a gap that could move such outcomes from being a hypothetical communicative tool to a research-driven one. The following diagram shows the wider theoretical location of the study.

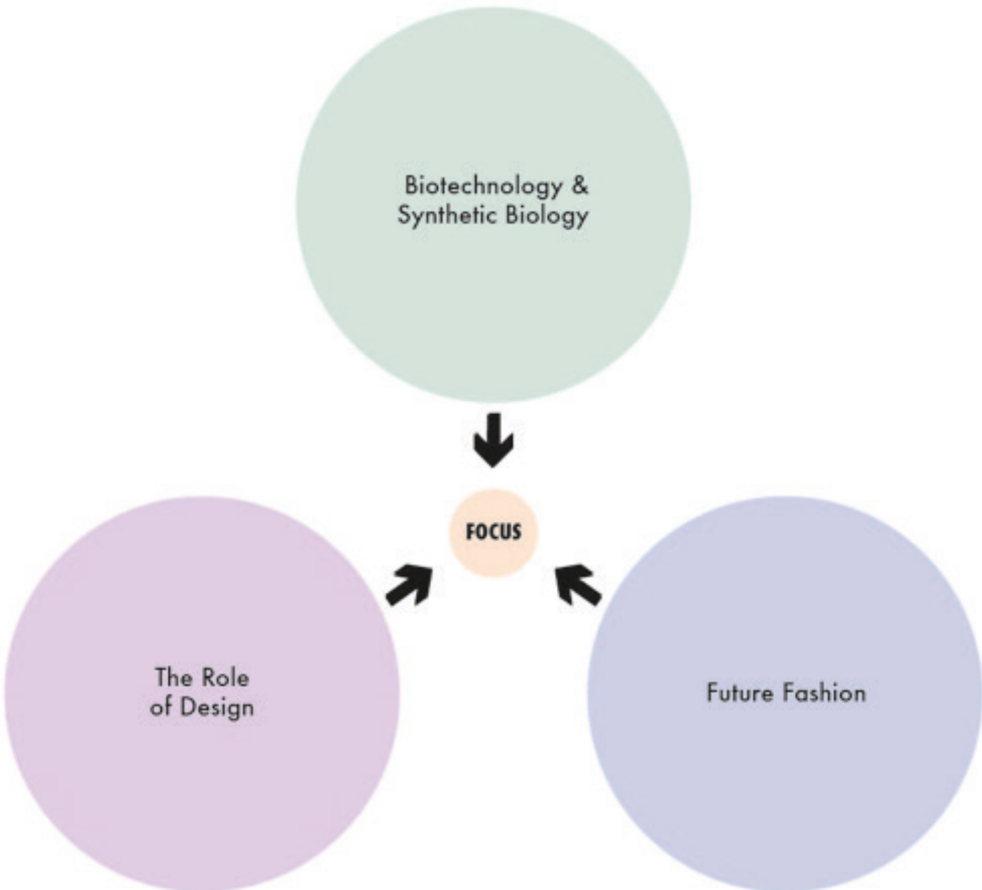
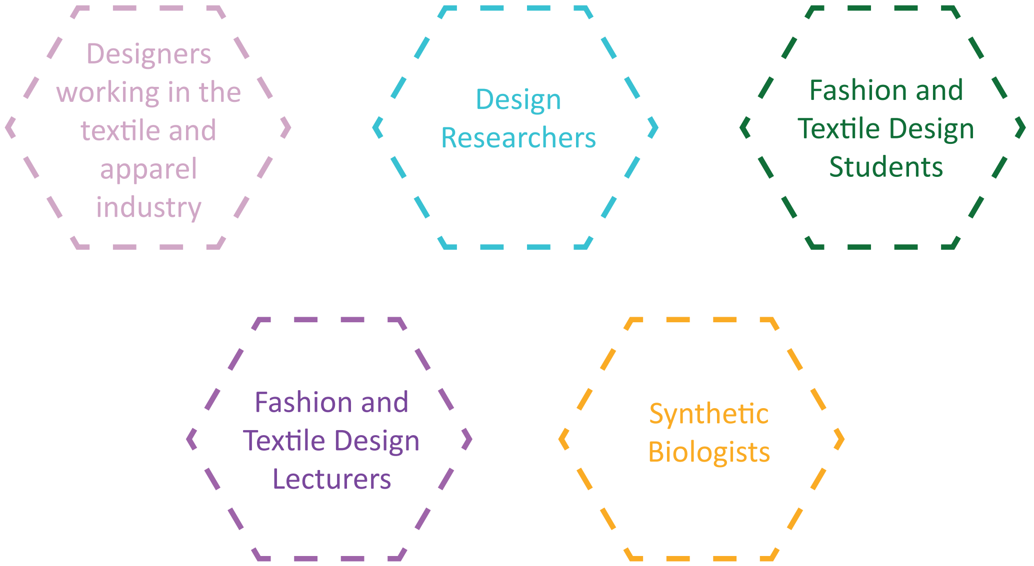



Fig 2: Theoretical Location Model, Hannah Hansell (2017)

## Audience

The intended audience for this research project is:




## Research Aims and Measures of Success

- The project aims to explore whether critical/speculative design approaches can be utilised to research and question the potential of biosynthetic technologies in the textile and apparel industry.
- It aims to review the existing and emerging landscape of biodesign, biotechnologies, synthetic biology, biodesigners, bioartists, bio start-ups and emerging design paradigms based on cultivation, growth and living cells.
- It aims to explore whether biosynthetic technologies could offer sustainable solutions, new materials and circular models, to tackle key industry issues.
- It aims to create work that can be exhibited or utilised in education settings to insti gate debate about the role of design in SB by future designers and design educators.
- It seeks to create a series of design objects/speculative provocations that pose and address the research question.
- Its measures of success will be whether it achieves these aims.

# Research Question

As the Textile and Apparel Industry moves into a new age of Biosynthetic-Technology, how will the role of design change and what design challenges and opportunities will arise?

# 02: Review

# State of Play in the Textile & Apparel Industry

## Introduction

This chapter explores the current position of the textiles and apparel industry, our relationship with and connection to fashion and textiles. It does this through reviewing theory from subject specialists such as Kate Fletcher, Safia Minney, Carole Collet and Jonathan Chapman. It takes the position of exploring the challenges and opportunities of the industry through the lens of sustainability. The relevance of this chapter in relation to the overarching aims of the project is that is presents the current state of play within this industry and landscape that I am faced with as a sustainable design researcher. It aims to draw out the key threads of the challenges that need to be addressed and the facets that need to be celebrated and protected. This chapter therefore aims to set out the potential areas that biosynthetic technologies could address and the further challenges it could raise.

## Fashion, Textiles and Sustainability

> *"Fashion Design has made a transition from a 'world-making' to a 'world-breaking' enterprise. As the complexity, pace and scale of the industry have increased, so too have its social, economic and ecological impacts (Chapman, 2016; 75)."*

Fashion and textiles are a central part of our lives and have been for generations. We rely on them for protection, identity and supporting our wellbeing, but our relationship to them is complex and often imbalanced. Human beings needs and desires are insatiable and our desire for pleasure, new experiences, status and identity formation, are often being requested from our clothing. Such complex requests combined with rampant fashion cycles and shifting trends contribute to very high levels of individual material consumption and expectation that are unsustainable. It can be said that we are indulging in temporary forms of fulfilment from our clothes at the cost of our environment.

> *"Human destruction of the natural world is a crisis of behaviour, and not one simply of energy and material alone, as is often assumed; the decisions we make as an industry, the values we share as a society and the dreams we pursue as individuals collectively drive all that we accomplish, while shaping the ecological impact of our development as a species (Chapman, 2016: 75)."*

In 2015, the total amount of clothing and textile waste in the UK per year was approximately 2.35 million tonnes. This is the equivalent of nearly 40kg per person, per year. The textile industry discharges billions of tonnes of waste and toxic chemicals from its production and manufacturing processes every year. Additional waste is created throughout the production cycle through the energy used, waste bi-products, air pollution and the strain on natural materials and land use. The human cost is also huge, employees in developing countries; Asia in particular, are often forced to work in unsafe conditions in relation to machinery, chemicals in finishing and dying and even unsafe buildings. Many of the chemicals used in fibre farming are severely toxic.

> *"Around 10 per cent of all chemical pesticides and 22 per cent of all insecticides used worldwide are sprayed on cotton crops. Cotton growers typically use many of the most hazardous pesticides on the market, many of which are organophosphates originally developed as toxic nerve agents during world war two." (Minney, 2011; 22)*

It is clear that the key challenges for the textile industry are changing the production methods, dealing with unethical, unsafe and toxic processes and, indeed, empowering consumers to help drive change. Most consumers are not aware of the socio-economic, cultural and environmental exploitation that takes place to enable a summer dress to be bought from a high street store for just £7. Instead the 'bargain dress' snapped-up on a sunny Saturday afternoon stroll through town is a perfectly innocent and satisfying purchase. This disconnected and linear system – from raw material to waste - enables the consumer to detach the object from natural systems. The manufacturing process itself causes further conflicts between 'object' and 'system'. Fibres are produced for manufacturers benefit - immune from biological decomposition – and far removed from their 'living' state.

Surely, what is needed is greater object longevity or even objects that can change and evolve with us. It is important that industry and designers help consumers recognise and understand the relationships between textiles and living systems. Greater awareness would enable consumers to consider materials and the fashion industry as living dynamic systems. This, in turn, may help facilitate moral questioning about the nature and consequences of current textiles production and enable consumers to adapt their day-to-day perceptions and habits to reduce the negative impacts of fashion culture.

Though there have been changes to the textile industry through improved legislation over the last 20 years, these have often only been incremental and are not at the pace required for a population growing at the rate it is (European Commission, 2011; Nuthall, 2011). It seems that in terms of design and manufacture we are still stuck within the economic model of the industrial revolution even when we are trying to take on more sustainable methodologies. Benyus describes the design and manufacture process of the industrial revolution as one that relied on the 'heat', 'beat' and 'treat' principle. We have begun to move on from these processes by trying to adopt the principles of 'reduce', 'reuse', 'recycle'. In seeking to achieve this endeavour countless methods, philosophies, and processes, have been developed 'upcycling', 'life cycle analysis', the 'circular economy' and 'design for disassembly', for example. However, the uptake of these practices by mainstream industries remains slow.

Whilst many of these strategies offer some improvements to resource efficiency and cleaner manufacture and design, they remain solutions only for the short to medium term. They do not tackle the fundamental issue of overconsumption. We continue to face the challenge of existing in an economy based on consumption and growth. A system that is exploiting natural resources at an alarming pace, resources that are becoming endangered and now polluted and even unsafe for us to be interacting with day-to-day. I believe we need to consider and plan for the future when the impacts of climate change and resource depletion will really hit us. How can we really move forward and explore new perspectives of manufacture and consumption?

Professor Carole Collet believes that,

> *"To readjust the balance, not only do we to acknowledge the issue, but I believe that we should begin to develop truly transformational technologies to help make a radical leap forward." (Collet, 2015; 192)*

In the Routledge Handbook of sustainability, Jonathan Chapman discusses how the fashion industry needs to advance and adapt to move towards a sustainable future. He discusses the need to develop opportunities to build resilience, discussing the potential of adaptive resilience, which allows us to stay true to a core purpose whilst being able to respond to and accept change.

> *"Striving to preserve the present, keeping things just the way they are, could be the greatest risk we are taking. Change is upon us; its time to adapt (Chapman, 2016; 77)."*

Can this change be driven by technology, in particular biosynthetic technology? Could the manipulation of microbes such as bacteria and fungus become a new way of crafting and producing textiles in the future? Carole Collet believes that, "Our future factories could be genetically engineered living cells, designed to custom-make materials to suit our needs." (2015; 191), suggesting that it could present (sustainable) opportunities for the fashion and textile industries. What will future sustainable textile manufacturing look like if we enter a,

> *"new era of biological engineering, where fabrics are produced by bacteria and the supply chains of fashion brands are genetically programmed" (Collet, 2015; 191)*

And what are the challenges and risks for future designers working with this emergent technology? The future challenges of a growing population, reduction in resources and changing environment need solutions that current industrial systems of production and manufacture cannot continue to support.

## Summary of Key Points

- The impact of fashion has moved from being an industry that is ‘World-Making’ to ‘World-Breaking’. This needs to change.
- The fashion and textile industry produces a vast quantity of waste at all stages of the lifecycle, new systems, production methods and materials could tackle these issues.
- Products are produced in a linear system; circular systems need to be adopted.
- Clothing is a key part of our identity formation, but we are asking too much of these objects in terms of temporary forms of fulfilment. We need to develop healthier relationships with our clothes, which in turn should develop a healthier industry.
- Toxic chemical use in processing is harming our environment, ecosystems and communities. We need to find ways to stop or reduce this pollution through less harmful substances and/or new processes.
- Consumers need to be educated in what they are buying and become more active in understanding their choices. Could ‘Living’ materials do this, objects that change and adapt with us?
- Could change in the industry be driven by biotechnology, specifically synthetic biology?
- Could the manipulation of microbes become a new way of crafting and producing textiles in the future?

# A New Age of Biosynthetic-Technology?

## Introduction

This chapter explores how and why we have used biotechnologies to manipulate life for thousands of years, cultivating, domesticating, cross-breeding and using living organisms for our pleasure, culture and desire. It goes on to look at the developing area of synthetic biology and what opportunities, challenges and risks could arise from this 'living technology'. It does this by reviewing theory and reports from biodesigners to steering groups, synthetic biologists, governmental bodies, and the inventor of the first synthetic cell, philosophers and bioartists. It takes from a broad range of writers in order to present a non-bias view by including a breadth of perspectives and opinion. It explains how synthetic biology was born and continues to develop, its functions and capabilities. It discusses its broader potential for condensed production of materials, different feedstocks, whether it can be sustainable, if we should engineer life, how the technology could be used in negative and destructive ways and whether we can and should be in control. The relevance of this section to the overarching aims of the project are that it aims to review this developing technology to see how it could offer opportunities and challenges if applied within the fashion and textile industry. It aims to draw out the potential areas that I can focus on and discuss/challenge through my final speculative narrative and objects.

## Domestication, Cultivation and Biotechnology

Biotechnology can be described as a discipline in which cells, cellular components, organisms and biological processes are used and exploited to develop new technologies and products. Modern biotechnology provides us with technology and products that reduce our environmental footprint, use cleaner and less energy, afford us with more efficient and less impactful manufacturing processes and combat rare and debilitating diseases. It is estimated that there are more than 250 biotechnology vaccines and health care products available today, more than 13.3 million farmers use agricultural biotechnology globally and 50 biorefineries being built in North America to produce biofuels (BIO, Unknown). Biotechnology is often sold as being a remedy to some of our key global issues around food, fuel and medicine. Sometimes shortened to 'Biotech', this industry has different focuses, processes and off shoots. For the creation of biofuel it uses biological processes such as fermentation and harnesses biocatalysts such as yeast, enzymes and other microbes to become microscopic manufacturing plants. For medicine it uses nature as a toolbox in combination with our own genetic make up. And for agriculture it improves crop insect resistance, enhances herbicide tolerance and facilitates the use of more environmentally sustainable farming practices mostly through genetic modification.

Biotechnology to some has already failed to deliver concrete results. However there are many examples of successful products from biotechnology in use today: protein digesting enzyme in biological washing powder made by bacteria, animal rennet substitute for cheese making manufactured by yeast and human insulin synthesized by e-coli. These products are not genetically modified but have been synthesized by GMO's. Many consumers are simply not aware of how these materials are made.

It is therefore important to remember that manipulating life is not new territory to human beings; biology is the source for our material library. Plants and animals are already designed objects. Natural cellulose is the base of cotton, flax, wood and paper. Rubber, cork, silk, wool, bone, horsehair, leather, shagreen, furs are all processed through/shaped by artificial technologies. Even our 'synthetic' materials, nylon derived from oil, come from dead organisms accumulated over millions of years. We have modified, cross bred and pollinated plants and animals for hundreds of years, designing these living organisms to our desired specifications. We have been domesticating and cultivating living species for at least 10,000 years for economic, personal and aesthetic reasons. Our drive to do this has been for culture, pleasure and intoxication. There are 50,000 known species of edible plants on earth, but 75% of our food intake comes from only 12 plants and 5 animal species. Of these, 3 provide more than half of the world's calorific intake – maize, rice and wheat. Since the beginning of the 20th century 75% of crop genetic diversity has been lost due to the increasing industrialisation of agriculture. Local variants have been ditched in favour of genetically uniform, high-yielding varieties. There has been a loss of flavour and nutrition with this optimization and a loss of diversity in fibres and yarns. Breeders and growers have rendered plants and animals into functional design objects over millennia. So is building new life from scratch, or modifying bacteria to produce and fabricate materials, food and medicine simply the next logical step or a further shift into monoculture and loss of diversity?

Whether cultivation, fermentation, crossbreeding or genetic modification, all of these processes use and adapt what exists; a different offshoot of this discipline still in its early stages is Synthetic biology. Synthetic biology can be defined as the design and construction of new biological parts, devices, and systems, and the re-design of existing, natural biological systems for useful purposes.

In 2012, synthetic biology was announced as one of eight key technologies by the UK government that would gain greater investment as part of boosting the economy. At this time it was projected that the industry would be worth $10.8 billion by 2016, it is now expected to be worth $38.7 billion by 2020. It is being marketed as having the potential to tackle major global issues in relation to energy, healthcare, the environment and material development by delivering new applications and improving existing industrial processes. Specific applications have and continue to emerge but largely it is an untapped industry in terms of its commercial potential with most advances and discoveries still in the research and development stage.

The UK was among the first countries to recognise and respond to the opportunities this translational and platform technology can offer. The first dedicated research centre in the UK, CSynBi was set up in 2009. The Synthetic Biology Roadmap for the UK was then published in 2012 at the request of the Department for Business, Innovation and Skills and put together by an independent panel of experts. The Roadmap has since been updated with 'Biodesign for the Bioeconomy: UK Synthetic Biology Strategic Plan 2016'. In these four years the co-ordination group has realised the growth opportunities for the Bioeconomy and Synthetic Biology's potential to address global challenges. The recognition of the importance of this new technology has put the UK into the front running as a world leader. This has also been supported by the establishment of six research centres in the UK and the aim for the market to develop to be worth £10billion in the UK by 2030 (UK Synthetic Biology Strategic Plan, 2016).

The adoption of synthetic biology in industry may move the chemical industry away from the highly centralised petrochemical industry to small-scale distributed production, enabling flexibility to produce a range of products. "Biology is the ultimate distributed manufacturing platform" (Ginsberg, 25) due to the scale of the machinery. Synthetic biology could be the third generation of biotechnology. But what is it exactly, how is it developing and what are the opportunities and challenges that could arise?

## Synthetic Biology - Operating System and Machine

> *"Synthetic biology is the design and engineering of biologically based parts, novel devices and systems as well as the re-design of existing, natural biological systems…It has the potential to deliver important new applications and improve existing industrial processes across many sectors including healthcare, energy, pharmaceuticals, materials and remediation – resulting in economic growth and job creation (UK Synthetic Biology Roadmap Coordination Group, 2012: 12)."*

Synthetic biology is a process where scientists can reprogramme cells to replicate products found in nature, and make specialised materials that would not normally be produced in a natural organism. Synthetic biology was born due to a deepened understanding of biological systems in combination with advances in DNA sequencing and synthesis. With chemistry and physics being mastered by the scientific community in the 20th century it seems that it is now the time of biology in the 21st century. Craig Venter and his team in the USA created the first self-replicating synthetic cell in 2010. 'Synthia' as it was named was the first synthetic bacteria and living organism with computer-engineered DNA. What Venter proved was that it was possible to decode the biological alphabet and control it by rewriting an entire genome. Up until this point scientists had only managed to genetically modify a species. But thanks to Venter and his team it is now possible to recode DNA sequences much like programming a computer, we can install a new operating system into bacteria in order to make it run and function in the manner we desire. Bacteria in this case become manufacturers and proteins become tools.

"In essence, scientists are digitizing biology by converting the A, C, T and G's of the chemical make-up of DNA into 1s and 0s in a computer. But can one reverse the process and start with 1s and 0s in a computer to define the characteristics of a cell? We set out to answer this question. (Venter, 2010)"

To explain the process in more detail information stored in DNA flows via RNA to instruct proteins and therefore the organism's behaviour. DNA is like an efficient factory with skilled workers making quality products. It has the blueprints, instructions for making, specialised workers and systems for precise function. Each cell has a single copy of its genome, a complete information repository from DNA. It is not just a blueprint, but also a complete instruction manual. Transcription is a shorter string of DNA written onto a new molecule. This information is then contained in the RNA. Many copies of RNA can be written from a single section of DNA, allowing subroutine instructions to go out to workers.

The final step is translation, where ribosomes read the commands of the RNA and use them to make protein molecules. Replication is the final important information storage process where a complete copy of the DNA is passed on when a cell divides.

As well as this reprogramming, synthetic biology is also gaining the ability to create new living organisms that have not existed on the planet before. Biobricks are standardised biological parts made from DNA that can be assembled using plasmids to make biological 'circuits'. If we can now re-programme living things such as cells are we on the verge of revolutionising the way we design things?

> *"The concept of biological evolution has just been transcended by synthetic biology: we can create life from the 'bottom-up', by hacking and manipulating raw biological blocks. We are now witnessing the convergence of synthetic and systems biology together with nanotechnology, genetic engineering and information systems and this creates a new type of technology, one that has the power to be alive and to behave like living systems (Collet, 2012: 4)."*

Synthetic Biology could therefore also be understood as a 'platform technology' or a 'living technology' with the potential to develop new industrial processes and manufacturing.

> *"For more than a century, industrial production has been dominated by the conversion of fossil oil-based feedstocks. The development of synthetic chemistry techniques in the 19th century through to the 20th century provided the 'platform technology' required to create new industrial processes and products using these feedstocks. Synthetic biology may provide the 21st century 'platform technology' required to create new industrial processes capable of producing and using a wider range of bio-based feedstocks generating a greater diversity of products, and supporting the expanding Bioeconomy with innovative solutions." (UK Synthetic Biology Strategic Plan, 2016).*

Professor Carole Collet believes that living technology will challenge the way that we design and consume products and the manufacturing processes we currently engage with (Collet, 2012: 5). It seems clear to those involved that this technology will continue to play a key role in our future lives, whether it can support us to develop a more sustainable way of life is still to be seen. But there is a growing argument that this 'living technology' can provide us with a set of solutions to some of our developing and projected future environmental problems.

> *"Living systems have a remarkable range of distinctive useful properties, including autonomous activity, sensitivity to their environment and robustness in the face of environmental change, automatic adaption and on-going creativity. There is increasing need for technology that has these features; such technology could be said to literally be alive…so the future of intelligent autonomous, automatically adaptive systems will be living technology." (Bedau, Parke, 2009; 7)*

If biology can become machine and material what are the possibilities that could affect the material, manufacturing systems and aesthetics? And what are the implications of an unstable and possibly destabilizing technology on our lives? Can it really provide us with solutions to our environmental issues and is it more sustainable than industry today?

## Is it Sustainable?

Can Synthetic Biology really be a sustainable solution? In many ways this is a paradox. Design and industrialisation are oriented towards growth, not equilibrium and sustainability. Can commercial synthetic biology ever be a sustainable, renewable technology when we have finite resources? As Collet states *"how can an extreme genetic-engineering science be portrayed as an ecological champion?"* (2015: 195) She questions whether its potential to be a champion lies more in the kinds of substances that can be produced rather than the process of engineering itself. And the potential breadth of its applications from biofuels to bioplastics, medicine, food, bioremediation such as wastewater treatments and carbon capture.

> *"Synthetic biology has the potential to generate a broad range of useful applications. It can be applied, for example, to develop smart response systems such as biosensors; to engineer plants for disease and drought resistance; to engineer mammalian cells for drug testing, stem cell production or tissue engineering; to engineer bacteria for human digestive and environmental health, and for waste management." (UK Synthetic Biology Strategic Plan, 2016)*

All of these applications show the technology's potential to tackle challenges relevant to current environmental and health concerns in the short to long term. This, it seems, is really where the connection lies to sustainability, as there is great potential to tackle some of the key sustainability goals set out by the UN. There is still much development work to be done however to move this area of science to mainstream large scale manufacture and many ethical issues to risks to consider and develop effective strategies and polices for. So what are the key issues that might be barriers to it truly being a sustainable alternative?

## Biology Needs to Eat

Biology needs to eat and synthetic biology feedstocks can be unusual, unethical and expensive; such as foetal calves stem cells being used to develop Modern Meadows tissue culture leather. They can also be cheap, such as the use of sugar to grow bacterial cellulose. Currently the bioeconomy is being sold as a sweet remedy to our dirty carbon and dangerous nuclear habits as an alternative sustainable glucose-powered future (Ginsberg, 2015). But this so-called green alternative might not be as sustainable in the longer term as hoped.

If this industry relies on feedstocks such as sugar, the effect of sugar cane production at a large scale on land use, the microbiome and communities could be just as harmful as cotton. Considerations as to the effect these microscopic systems will have globally when scaled up need to be explored. Will there be enough land to feed our cars, planes, products and clothing, ourselves and our livestock? Can such large-scale monoculture farming be sustainable? (Ginsberg, 2015)

## 1st Generation Monstrous Hybrids

There is also a danger that synthetic biology could become a way of simply pumping out more ‘stuff’, fabrics and garments that already have key issues; that it might create its own ‘monstrous hybrids’ to meet demand (McDonough, 2002). Bacteria that creates acrylic acid for plastic or isoprene for rubber, both non-biodegradable and once put out into the world, as a product may be no less harmful or polluting than their current counterparts. If we are not careful this developing technology could take the same route of industrialisation creating a first generation industrial biotechnology (Ginsberg, 2015). It might end up giving a ‘green gloss’ to harmful practices like excessive consumption, inefficient production and toxic waste.

If we look at existing natural systems where engineering has been applied such as industrial agriculture, the model of standardisation and simplicity of using mono-culture chemical based systems have cause ecological issues and reduced biodiversity. Could such biological monoculture manufacture cause similar problems? Environmental risks need to be considered if products are designed to be compostable and enter into the micro biome. Organisms released into the earth will require biosafety regulations and intellectual property control.

## Controlling and Patenting Life

One of the main challenges and risks for this technology is the ability to control life. Working with cells that can self-replicate and controlling their growth is complex task with moral and ethical concerns. Reprogramming existing living cells involves the risk of the cells escaping a controlled lab and having an impact on existing natural habitats. There are also moral questions about who is in control. Can and should we control life and what if synthetic organisms take charge by ‘overriding’ what they have been programmed to do? Will they evolve into uncontrollable and potentially destructive organisms? If there is the potential to engineer these organisms’ functions there will be the potential to engineer and programme cells to only survive in certain conditions or to self-destruct once they have done their job. An element of a fail-safe can be designed in to give some control, but will this be enough?

There are also key questions about patenting and ownership of living reproducing things that need to be asked. It may seem essential that such synthetic DNA must be owned but the use of open-source in synthetic biology has been essential to the industries development so far. Tina Gorjanc’s project Pure Human addresses these issues of patenting through the use of speculative design. The pure human project is a critical design project aimed at addressing the shortcomings of the current protection or lack of biological information. The project explores the possibility of how biotechnology, genetic modification and bioengineering could change the luxury goods market, as we know it. The outcomes of the project are a series of conceptual commercial accessories that have been cultivated from human biological material, in particular that of the late designer Alexander McQueen. Gorjanc aims to instigate discussion into the current legal structure and highlight key biolegal issues that will need to be addressed as this industry moves forward. What is interesting about the work is the amount of media attention the piece has gained with many articles believing that the work was real. Gorjanc was successful in creating debate around the ethical and legal loopholes at present through the actual application and approval of a patent.  And through the overall narrative that the objects and project as a whole presents.

Fig 3.1: Pure Human, Tina Gorjanc (2016)

Fig 3.2: Pure Human, Tina Gorjanc (2016)

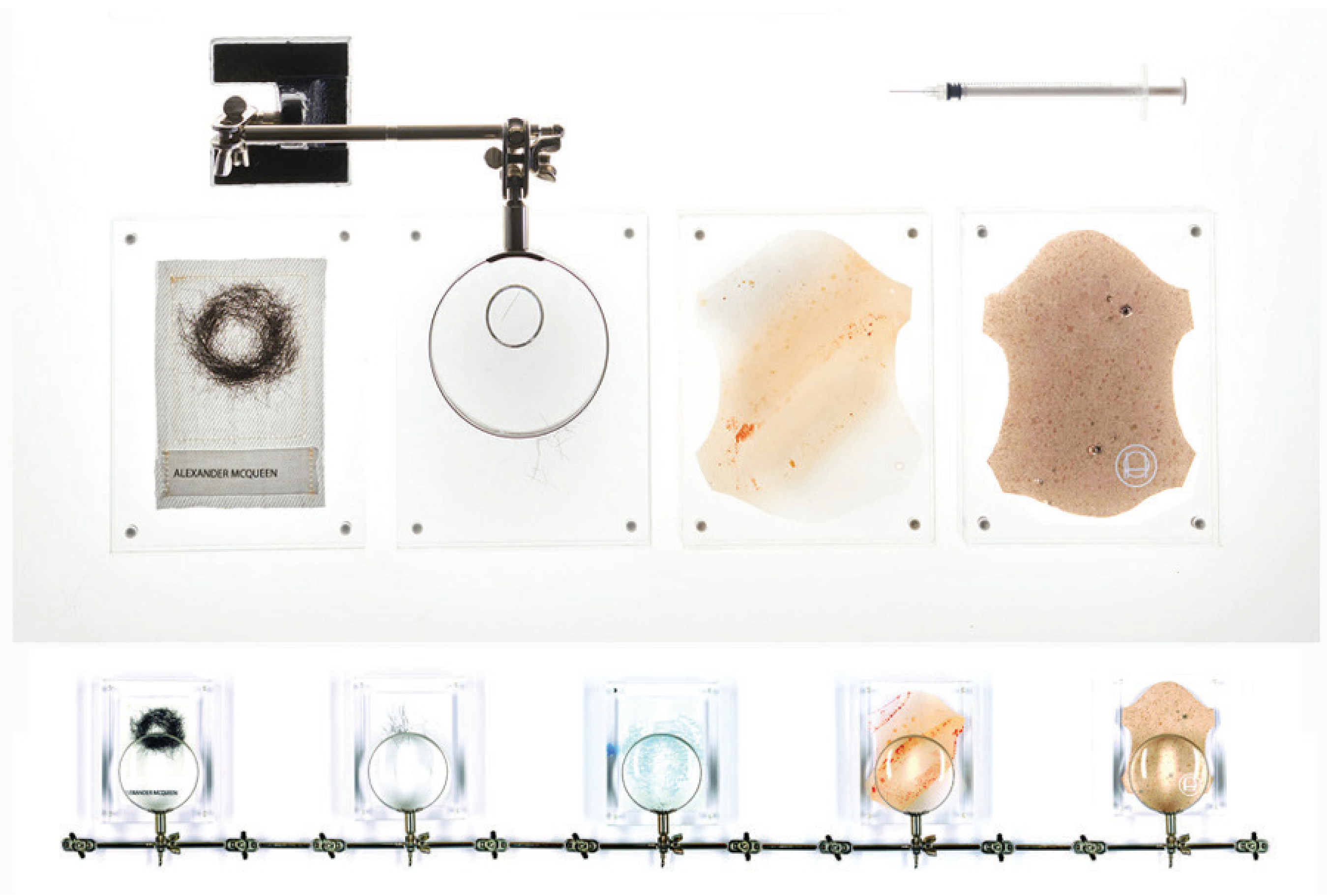



Fig 3.3: Pure Human, Tina Gorjanc (2016)

The concerns raised by Gorjanc are essential discussions that need to be had with the rapid development of the industry. Control, ownership and regulation are complex issues that need consideration. An even more ethically concerning consideration however is if we can control life, will we start to control death?

> *"An Even bigger change in the technology of the future, compared to that of the past, is that a nuclear bomb though hideous in its potential, cannot self-replicate; but something that might – nanobots – could soon be taking over the planet." (Greenfield, 2003; 5)*

There are currently a number of reports, policies and advisory groups nationally and internationally that are supporting the increase of funded research, attempts to define and direct the industry's development and focus and clear suggestions of opportunities, risks, ethical guidelines and support systems to foster greater understanding about this technology during its development. The industry does seem to be moving at a rapid pace however, fuelled more by its potential as an economy and its current and future projected worth. This raises concerns about the safe use and production of living matter.

Another challenge for the industry is effective public engagement and communication with this technology. A report from the Symposium on opportunities and challenges in the emerging field of synthetic biology discussed at the time a drive from both within and outside the synthetic biology community for the importance of public engagement and participation in the development of this emerging technology. A key point coming from this symposium was the optimistic view of Adam Bly (Founder, CEO, Editor in Chief, Seed Media) that the synthetic biology community has an opportunity to reform science communication based on three factors,

> *"A shared sense of social responsibility within the synthetic biology community will appeal to the wider public; synthetic biology has the potential to be a participatory science; the open and transparent forms of communication currently preferred by many within the community are readily transferable and already accessible to the public." (OECD, Royal Society, 2010)*

There is also concern around issues of bio-security and bio-terrorism and of the direction of intellectual property. Can we and should we patent the living? (Baldwin et al., 2012:136) Groups such as ETC have produced lengthy reports on the industry discussing concerns around bio-terrorism and bio-hacking as a potentially more perverse use of the technology (ETC Group, 2007), all key concerns that need to be discussed. It seems that staying in control of this technology along with developing clear ethical guidelines for any development of such products into industry will be a top priority. But is such tight control of life the path we want to tread? What moral and cultural issue does this raise?

## Engineering Life

Oron Catts and Iona Zurr believe that life is being seen as a new space for exploitation. Life is being extracted from its natural context and placed into the context of manufacturing. It has become a raw material to be engineered. They talk about a single engineering paradigm – a vision of the future in which the control of matter and life and life as matter will be accomplished through engineering. Creating a shift in the way life is perceived and used.

They believe that engineers are interested in SB because the living world offers a rich but unexplored medium for processing and controlling materials, energy and information. The dangers of breaking life down into something that can be engineered pave a potential path for human societies becoming objects to be engineered.

> *"Animal cells cannot manufacture nutrients from nothing; in vitro meat is merely an engineering exercise in translating/synthesizing nutrients from other sources. In other words, parts of the living are fragmented and taken away from the context of the host body (and this act of fragmentation is a violent act) and are introduced to a technological mediation that further abstracts their liveliness." (37)*

Creating this new semi-being life that relies on us for survival creates new life that could be exploited. This is due to the abstraction of what life is and a blurring of boundaries between living and non-living. They believe artists expressions that are subtle and complex can offer possible and contestable views and directions of synthetic biology. That they can counter the engineering trait of control that it should not be allowed to monopolize life. Could exploitation and monopoly being avoided if such a developing technology advanced in different settings, such as the home DIY environment?

## Domesticating Biotechnology

> *"Will the domestication of high technology, which we have seen marching from triumph to triumph with the advent of personal computers and GPS receivers and digital cameras, soon be extended from physical technology to biotechnology? I believe that the answer to this question is yes." (Dyson, pg.1)*

In his article "Our Biotech Future", Freeman Dyson suggests that just as the domestication of the computer has dominated the last 50 years of human lives, so will the domestication of biotechnology for the next 50 years. Dyson believes that genetic engineering is likely to remain controversial and unpopular so long as it remains in the hands of large corporations (Monsanto an example) and as a centralized activity. He is interested in the potential and positive path biotechnology could take if it becomes small and domesticated like the path of the home computer.

> *"Domesticated biotechnology, once it gets into the hands of housewives and children, will give us an explosion of diversity of new living creatures, rather than the monoculture crops that the big corporations prefer. New lineages will proliferate to replace those that monoculture farming and deforestation have destroyed. Designing genomes will be a personal thing, a new art form as creative as painting or sculpture." (Dyson, Pg.1)*

It seems at present that Synthetic Biology's rhetoric is to address humanities needs rather than our individual complex needs. Ginsberg believes that even though it is presented as a disruptive technology it also promises to do nothing. It will simply substitute the existing mechanical machinery with biotechnological processes to produce the same materials. There is potential for real development and change to be over looked, of the novel design opportunities and the unique issues that such a living technology presents. It is clear that this needs to happen through reflection and cultural analysis.

## Summary of Key Points

- We have been manipulating life for hundreds of years, is the next step of modifying organisms synthetically an inevitable step?
- Will this technology and method encourage greater diversity or will it just develop a synthetic based monoculture.
- We need to look to the diversity of species that exist on our planet and consider diversity through smaller scale sources.
- We already have products that have been within industry for some time synthesized by GMO's.
- The UK is one of the leading figures in supporting the development of Synthetic Biology.
- The industry offers the potential for small-scale distributed production, moving away from the petrochemical centralised, mass production model.
- Synthetic Biology allows us to design and build from the 'bottom up' new organisms and 'top down' adapt existing. This offers the opportunity to produce existing materials more efficiently and from new sources and completely new materials.
- If we can now re-programme living things such as cells could we be on the verge of revolutionising the way we design things?
- Designers can play a key role in advising on the development of this technology bringing knowledge from each stage of the lifecycle of a product.
- It is unclear yet as to whether it can be more sustainable solution. We might simply be switching our energy source to glucose and therefore similar monoculture farming, with the same or even more challenging large-scale effects.
- First generation industrial biotechnology might end up giving a 'green gloss' to harmful practices like excessive consumption, inefficient production and toxic waste.

- Issues around control, IP and patenting of living organisms raise questions that are morally and ethically complex. How much control should we have, who should have control and what failsafe's need to be put in place to protect the microbiome?

- Critical design is being used as a tool to instigate debate around future issues through narrative.

- There is a danger that engineering biology will just produce more matter with the same production, consumption and linear systems that it does now.

- There are issues around such a technology and organism's falling into the wrong hands and being used for bioterrorism, being hacked in order to carry out harmful acts.

- These dangers of exploitation and monopoly also encompass the human genome as a space to be engineered. In the creation of new life, existing life becomes abstracted, artists and designers can play a cultural role in highlighting such potential monopolisation of life that engineering cannot.

- Could this route be avoided if we embraced the development of this technology through DIY, domestic biotechnology? And would it be a path where consumers are more likely to embrace this new paradigm and technology?

- There is potential for real development and change to be over looked, of the novel design opportunities and the unique issues that such a living technology presents.

- It seems at present that SB's rhetoric is to address humanities needs rather than our individual complex needs. Critical reflection and cultural analysis need to be used to understand it's most effective path.

# A New Paradigm of Production: Factories of the Future

## Introduction

This chapter will explore whether we are entering a new industrial age and paradigm of production instigated by new living technologies, environmental challenges, resource depletion and growing breed of designers, start-ups and companies dedicated to reducing the impact products have on the planet. It will discuss contextual examples of organisations, events and practitioners/companies who are driving what they claim to be a 'material revolution'. And will highlight some of the key research, organisms and processes being used to shape this new paradigm. The relevance of this chapter in relation to the overarching aims of the project are to review examples of existing designers, artists and companies addressing key planetary issues by rethinking the matter, processes and systems we use to make things with. It aims to highlight what currently exists in order to consider further areas for development and/or potential models to utilise in the creation of my speculative narrative and objects.

## Are We Entering a New Inudstrial Age?

The environment is challenging us, but alongside this there is a materials revolution happening. A new paradigm of production has begun to emerge. One based on cultivation and growth, much closer to agriculture, cooking and brewing than the petrochemical industry. Some of these processes utilise ancient methods of brewing and cultivation, others are looking to biotechnology and engineering organisms to produce biosynthetic materials, others driven by robotics, AI and IOT. Professor Klaus Schwab founder and executive chairman of the World Economic Forum and author of 'The Fourth Industrial Revolution' discusses this next stage of industry characterised by new technologies that fuse biological, digital and physical worlds. He discusses how this new age will affect all economies, disciplines and industries and how this could happen at an unparalleled pace. Some of Schwab's observations and reflections aren't breaking news and at times he sit's on the fence and doesn't take a solid position. Schwab states that there is both potential and peril in this future industry, something that is fairly obvious,

> *"The changes are so profound that, from the perspective of human history, there has never been a time of greater promise or potential peril." (Schwab, 2016)*

Observations and discussions that are interesting however are how he describes the potential fusion of the technologies involved in this future industry. How he believes that this will make the industrial revolution different from the past,

> *"It is the fusion of these technologies and their interaction across the physical, digital and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions." (Schwab, 2016)*

This potential marriage and collaboration of technologies opens up great potential in the way that we might make things in the future, the systems we develop in manufacturing, the functions of objects and the data we can collect and analyse from products during use and at end of life. If we think about these merging worlds what could a biological garment combined with the technology of IOT offer us? Data on its use, wear, its owners interaction and connection to the garment. We could connect to out biogarments in their biowardrobes through our phones.

> *"The more we think about how to harness the technology revolution, the more we will examine ourselves and the underlying social models that these technologies embody and enable, and the more we will have an opportunity to shape the revolution in a manner that improves the state of the world."*

A vital point made by Schwab is that we need to shape this revolution in away that improves the world, our environment and through sustainable practices. Alongside these theories it seems important also to consider the question of whether we could actually be moving from 'hand-made' and 'man-made' to 'grow-made' as a production process suggested by Professor Carole Collet. Will we eventually move away from machinery completely and look to biology as system and factory? To explore why this shift is occurring lets review examples that suggest a new industrial age might be just around the corner.

Fig 4.1: Basil n 5, Carole Collet (2010-12)

## Biofabrication and Biofacture

A key influencer advocating the potential shift to a new paradigm of 'biofacture' as she terms it is Professor Carole Collet. Collet's research interest lies in exploring biological principles and living technology through design to create a more resilient future. She explores Living Technology, Synthetic Biology and Biomimicry for Sustainable Design, with an aim to develop compelling material, technology and design-led Innovations. She is interested in how we can generate new sustainable design and manufacturing tools.

Collet's research into plant architecture, biological morphogenesis and synthetic biology makes us think about how we might manipulate plant cells to grow and pick our own luxury textile products in the future. Can and should plants be genetically modified to produce products for us? Her post 2050 design scenario presents the idea of combining food and textile production. Can plants be designed to replace textile machinery whilst also providing food? Biolace is a series of design probes presenting the potential of synthetic biology for the future manufacturing of textiles – what Collet calls 'biofacture'. Collet believes that there is an emerging biological revolution and with this a new toolkit that will allow us to engineer and program life

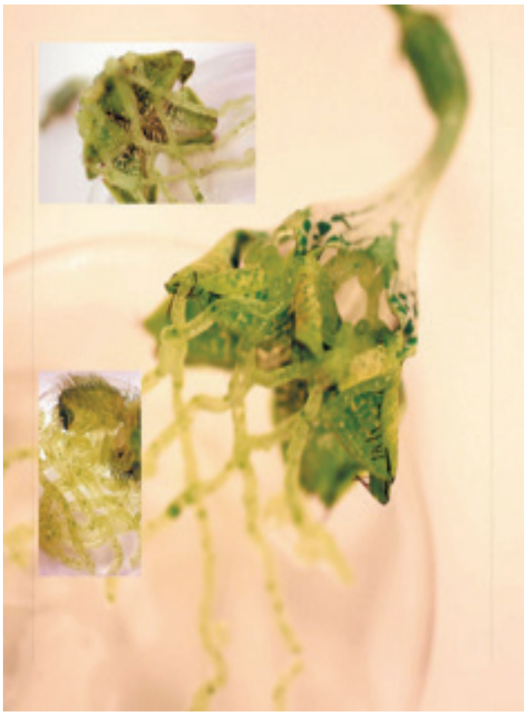


Fig 4.2: Biolace, Carole Collet (2010)

from scratch. With this she believes that there is a need to re-evaluate designs position and potential. She believes that we need to develop a critical understanding of how we can shape a truly ecological age in the future.

Biofabricate; founded in 2014 by Suzanne Lee of Biocouture ™, is a conference focused on nurturing collaboration around the field of biodesign and biofabrication. It is a space where knowledge is shared, community is built and innovation is fostered and a key event advocating this 'material revolution'. As an annual conference it brings together designers and scientists, artists and engineers, global brands and start-ups, investors and policy makers, trend-forecasters and media from around the globe. The conference's focus is not on the biomedical definition of biofabrication but on bio-innovation that is emerging in a range of fields from the arts to design to startups, biohacking, synthetic biology accelerators and research-led studios. It creates a space where all of these industries can come together driven by creativity, sustainability and environmental responsibility, exploring materials and processes that utilise living systems.

Key speakers at this year's conference are advocates of this new material age and paradigm. Suzanne Lee the founder being a catalyst and advocate of working with microbes. Lee originally founded the London based design studio and consultancy, Biocouture, pioneering the use of biomaterials for the fashion, sportswear and luxury sectors. The studio explored organisms like bacteria, cellulose, fungus, algae and yeast and they're potential for growing and producing fabrics and apparel. Some of her key outputs can be seen below where Lee used the process of brewing sustainable fabrics; biomaterials, using similar processes to making kombucha tea with mother culture as the scaffolding for growing bacterial cellulose, which once dried and sterilised, have similar properties to leather.

Fig 5: Biocouture Garments – Bio Bomber, Bio Biker and Eco Kimono Suzanne Lee (2010)

# BIOFABRICATE

## DESIGN, BIOLOGY, TECHNOLOGY: GROWING A BETTER FUTURE

Lee's interest started from a conversation with a microbiologist and developed through her interest in the potential for growing material using microbes in relation to it's potential sustainability and developments in public understanding that the micro biome around us and in us is covered in bacteria that keep us alive. Microbes and bacteria that we rely on for our health and wellbeing. Lee believed that this could offer the opportunity for such biomaterials to start to be accepted by the consumer more readily. Alongside this were many other advantages such as material production through the fermentation method being fairly low-fi and such production on a larger scale having even greater advantages. The portfolio of fabrics that we currently work with in the fashion and textile industry has a very long supply chain and is a wasteful and harmful system. The process of using fermentation and a living organism creates little waste. The fibre is both being produced and organised into a material, you are able to grow that into the shape you require. It's a closed loop system, with low environmental impact; Lee advocates that the sustainable footprint is incredible. There is also a reduction in cost because everything can be created in one place from material to product. Another interesting aspect is that the engineering happens at the smallest scale of the cell. So from a design and performance perspective working with bacteria or yeast for example you can engineer the fabric to the finest details.

In terms of consumer care the material could have a massive impact on the aftercare of clothing and textiles. A biomaterial could be re-submerged into the solution it is grown in to mend and repair the garment. It could also be put into a nutrient soaked solution to revitalise it or a specific bacterial solution that would clean it. This would completely revolutionise the washing and laundering processes, as we know them today.

Lee currently works for the silicone valley start-up Modern Meadow as their creative officer. As a bioengineering start-up Modern Meadow are using living cells to grow materials, making biofabricated leather in the lab, free of animals. Moving forward from the consultancy her position at Modern Meadow and the founding of Biofabricate has put Lee as a central advocate of this material revolution.

A key speaker at the 2016 Biofabricate conference Maurizio Montalti of Officina Corpuscoli has been working with fungus for a number of years now through 'the growing lab'. As an on going design research project 'the growing lab' seeks to explore and assess methodologies for the development of novel materials and processes focused upon mycelium. Montalti has been exploring the central question - "What is the potential of high-biotech, craft-based thinking, when combined with open-source, made-to-measure processes?" The project focuses on exploring the potential of mycelium replacing petro-chemical based materials, moving from toxic to natural, compostable matter and circular systems. Fungus feeds off of waste matter and therefore as a material has a number of benefits in its conversion of waste and ability to 'pay forward'. Montalti states,

> *" 'The Growing Lab' aims to indicate unprecedented paths regarding the generation of better and economically sustainable production possibilities, transforming current existing paradigms, systems and networks, suggesting a shift from the traditional concept of industrial production towards an innovative model, rooted in cultivation." (Montalti)*

Montalti's goal is to move beyond the existing production systems into a paradigm that will bring a new landscape of 'cultivated' objects into our lives. 'The growing lab' seeks to develop collaboration with natural systems and to propose a new economic production model. Maurizio is also the co-founder of Mycoplast, a company focused on scaling-up mycelium based materials, services and products to an industrial scale. What is also fascinating about his work is how he embraces the aesthetic of this fungal material, rather than trying to force it to represent existing material qualities. He tries to work in symbiosis with the material.

Fig 6.: he Future of Plastics, Officina Corpuscoli (2014)

Fig 6.2: The Future of Plastics, Officina Corpuscoli (2014)

Fig 6.3: Mogu at Biofabricate, Officina Corpuscoli (2016)

Bioesters, the winning team from the 2016 Biodesign Challenge, presented their project outcomes at the 2016 Biofabricate conference. The team from FIT created a bio-based material to try and address the harmful impact of the fashion and textile industries production methods. Made from a form of alignate, which is extracted from brown seaweed, they developed its usual production format of sheets into an extruded yarn. The bio-based filament can be knitted or woven by hand or machine. The team believe that this material could be the answer to creating a more circular sustainable economy for the fashion and textile industry.

The team have now set up as a research group called Algiknit. They are currently developing wearable textiles from a range of biopolymers. Their aim is to develop sustainable bio-based alternatives for the textile and apparel industry. To reduce the environmental impact and footprint of the materials used and the product lifecycle, using a closed loop system.

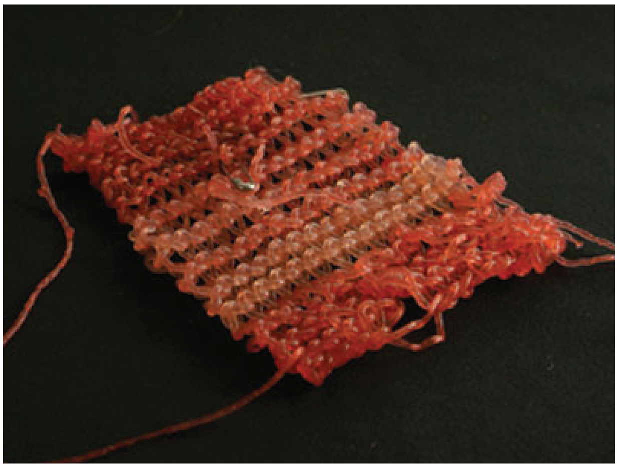


Fig 7.4: Logo, Algiknit (2017)

AlgiKnit

Fig 7.5: Material Samples, Algiknit (2017)

Fig 7.1: Algiknit, Bioesters (2016)

Fig 7.2: Algiknit, Bioesters (2016)

Fig 7.3: Algiknit, Bioesters (2016)

Adidas unveiled the new biodegradable shoe at the Biofabricate conference 2016 made from a new lightweight ultra strong 'biosteel' developed by AMsilk. Named the Adidas futurecraft biofabric, the sportwear giant has developed a shoe with the aim of being more environmentally friendly. The shoe can break down in under 36hours with the use of a particular enzyme. The biotech company AMsilk are know for their research and development into engineered spider silk. The material developed for Adidas is created using the same proteins that spiders use to make silk. AMsilk is also working on a range of other products including cosmetics made with the same base material. The shoe shows how biofactured materials are now beginning to enter into industry.

Fig 8: Futurecraft Biofabric, Adidas (2016)

Finally a key start-up company in attendance of the conference, Bolt Threads have developed the first bioengineered spider silk tie. Bolt Threads was given $32.3 million from Foundation Captial's Founders Fund, Formation 8 and Alafi Capital through a series B funding in order to take the production of a material they have developed from spiders silk to manufacture at industrial scale. Their plan was to make fabric by manipulating the genes of particular bacteria to get them to produce the same threads that spiders spin. The output is a fabric that is stronger than steel but at the same time softer than merino wool. Spider silk has been used for thousands of years to catch fish and heal wounds amongst other applications. It has the properties of being very elastic and stretch resistant whilst being 10 times harder than Kevlar or steel. The start-up is now working with a range of large textile companies who want to use this material for their products.

*"Our technology combines biology and computational methods to create performance fibres with carefully crafted properties. We're very excited to sustainably develop the next generation of performance fabrics that will transform what we wear and how we live." (Bolt Threads, 2016)*

In terms of existing fibre development silk has been the most successful fibre so far to be genetically engineered. The key benefit for using synthetic biology as a technology to develop an existing fibre by reprogramming bacteria to produce these threads is that it offers the potential for mass production which has not been previously feasible. Spider silk from its conventional source is hard to mass-produce in terms of quantities as this involves enslaving spiders that tend to get cannibalistic in close confinement. Also the amount of spiders needed to produce large quantities of the material was not a scalable model for the silk industry.

*"As a silk protein, its chemical composition is encoded in the genes of the organisms that make it. Researchers have unravelled this composition, but it is too complicated to just put silk together by hand using industrial methods. A better approach is to turn organisms into living silk factories." (Ball, 2011)*

Fig 9.1: Silk Knit Tie, Bolt Threads (2017)

Fig 9.2: Silk Knit Tie Advertisement, Bolt Threads (2017)

## Biohacking and DIYbio

As well as design studios, accelerators, artists and start-ups, there is another section of people pushing this new paradigm of production through hackspaces, community groups and DIY garage or kitchen based biology and material experimentation. London Biohackspace is an example as a community run molecular biology and microbiology lab based at London Hackspace in Hackney. The purpose of the lab is to provide access to lab equipment and bench space, for use in a safe manner, for individual or collaborative projects. London Biohackspace encourages members of all experience and backgrounds from amateurs and professionals of artists, engineers, biologists and programmers to carry out innovative bioscience projects. They believe that the strength of the biohacking and DIYbio community is the diversity of its members.

One of their on-going projects, JuicyPrint is a 3D printer that utilises bacterial cellulose, a strong and exceptionally versatile biopolymer, to create a range of shapes through additive printing. They have developed a genetically engineered strain of the cellulose producing bacteria Gluconacetobacter hansenii (G. hansenii). G. hansenii (sometimes referred to as Acetobacter) is normally found growing in vinegar and is used to make a fermented tea called kombucha.

Fig 10.1: Biohackspace Logo (2015)

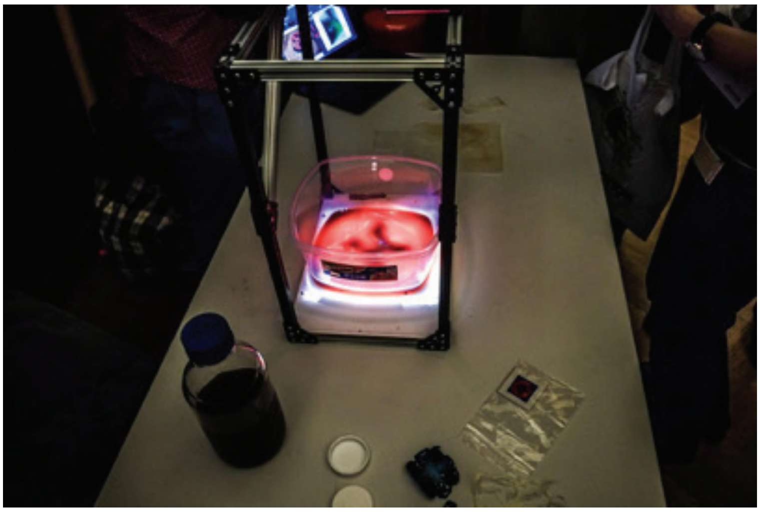


Fig 10.2: Juicy Print, Biohackspace (2015)

Their plan is to insert genes that will allow them to switch the cellulose production of the bacteria on and off using light. Cellulose usually grows on the surface of the liquid nutrients, but they believe that when a pattern of light would be shined on the surface of a liquid culture of the engineered strain, only the bacteria in the dark patches will make cellulose, therefore the cellulose could be made into any shape they want. If the patterned layer of cellulose is then pushed below the surface, a three dimensional structure could be built up out of the multiple patterned layers. This project has not developed any further than prototype and proposal. In terms of the cost and time involved in this production method it would not be viable for industry, as it would take such a long time to produce, waiting for each layer to grow.

What was interesting visiting the biohackspace was the diversity of people who use the space, the method of on going contact through the messaging platform 'slack' and the openness to collaboration, support and advice. The people using this space are passionate about experimentation, learning, open access to information and data.

Another example, set up in Brooklyn as the world's first community lab where anyone can learn and work on biotechnology is Genspace. Since 2009, Genspace have served the greater New York area by providing classes for adults, cultural events, STEM educational outreach and a platform for science innovation at a grassroots level. Genspace is definitely more advanced than the biohackspace offering a range of classes and workshops run by instructors from top institutions around the New York area. Workshops offered range from a bioart master class to biohacker boot camp, a biotechnology crash course to a fungal fabrication class, speculative biodesign to genome editing with CRISPR. The grassroots approach offers an opportunity for engaging the wider public in such new technologies and potential systems. To develop structures inspired by small, distributed centres that foster and promote diversity and breadth.

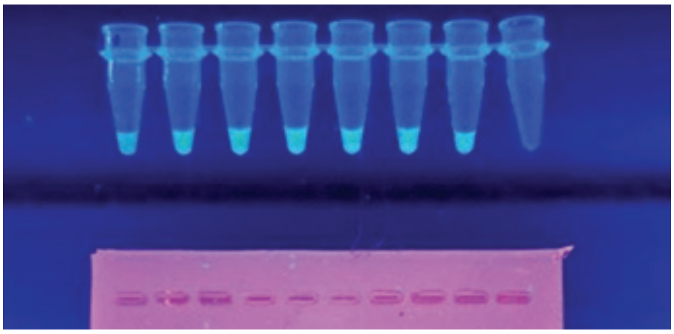


Fig 11.1: Workshop Promotional Image, Genspace (2017)

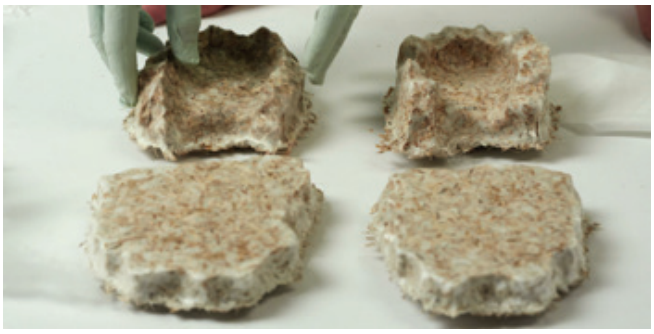


Fig 11.2: Workshop Promotional Image, Genspace (2017)

It seems important to mention designers working in this DIY manner such as Emily Crane who utilises skills from molecular cooking. Crane has a lab in her kitchen, where she is growing and freezing bubbles to create a form of bio lace that is both wearable and edible. Crane is trying to push the boundaries of design by growing, cultivating and shaping new hybrid materials for fashion futures.

> *"Through this unique process and development of new materiality I have laid an innovative creative foundation for future fashion design, conscious of the restraints of our future planet and the impact from current fashion cycles. My methods look towards 'survival' as a key factor informing my processes; fashion is no longer a thing of simple beauty, but of nutrition also." (Crane)*

She experiments with materials that occur naturally when cooked up from edible ingredients including gelatines, kappa carrageenan, agar-agar sea vegetable, water, natural flavour extracts, glycerine, food colouring and lustres. She describes is as high-tech kitchen couture.

Fig 12.1: Micro Nutrient Couture, Emily Crane (2010)

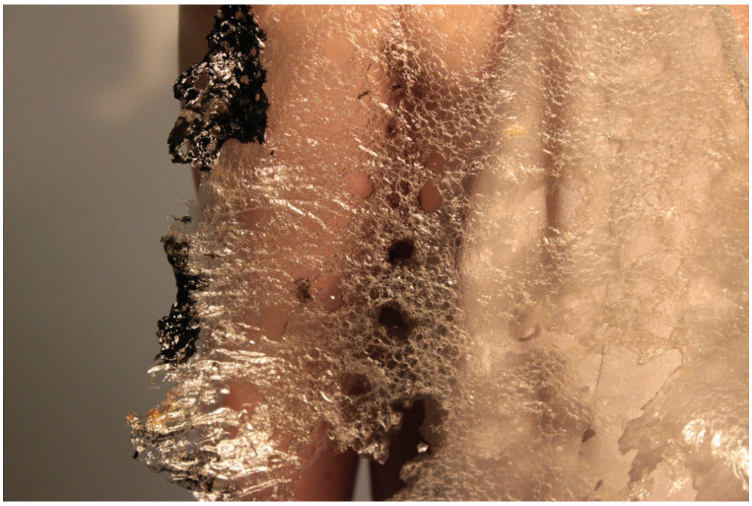


Fig 12.2: Micro Nutrient Couture, Emily Crane (2010)

Another example is the design researcher Miriam Ribul, who explores the dynamics that can be created through the interaction of textiles and materials with the environment, objects, space, clothing, and digital tools. 'Recipes for Material Activism' is part of the 'Embodied Energy Series', an on-going research project initiated by Miriam. Her aim is to research material and people focused processes for sustainable manufacturing through this series.

Fig 13.1: Recipes for Material Activism, Miriam Ribul (2013)

Fig 13.2: Recipes for Material Activism, Miriam Ribul (2013)

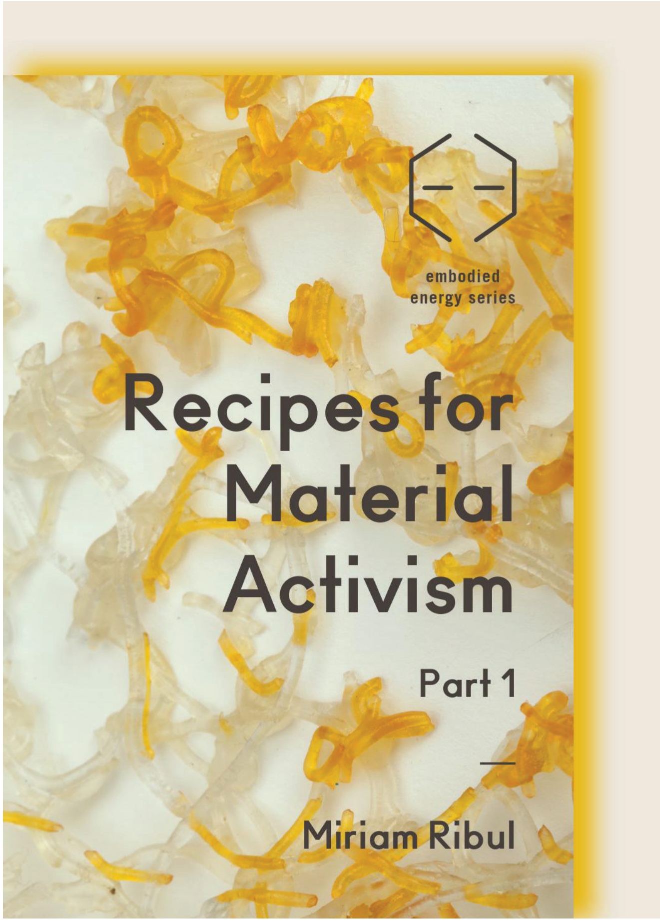



Fig 13.3: Recipes for Material Activism Book, Miriam Ribul (2013)

She explores new systems for material production that can lead to collaborative design and universal manufacturing. She explores physical properties of materials and new craft with a key interest in experimental textile design practice that can be translated into various scales – from the digital to the closest personal space. Is it in this space of DIY, community, hacking and material activism that we should be looking in order to find some of the methods, values and systems for this new paradigm?

## Summary of Key Points

- A number of designers, artists, start-ups and theorists believe new paradigm of production is emerging based on cultivation and growth, driven by a materials revolution.

- Conferences such as Biofabricate are creating spaces for the presentation of and discussion around bio-innovation that is emerging in a range of fields, most importantly driven by creativity, sustainability and environmental responsibility.

- Suzanne Lee is an example of a designer who has moved into the role of creative director at a bio-start up, she is an example of emerging intra-disciplinary and cross-sector companies and therefore product application.

- Lee’s original work at Biocouture show’s the possibility in the shift of production methods, design, aftercare and aesthetic if biomaterials are introduced into the fashion and textile industry. If it does become viable to scale up production we could see a radical shift in the way clothes are manufactured and cared for, to the benefit of the planet.

- Maurizio Montalti is another advocate for this new paradigm of production. As well as bacteria and yeast, mycelium and fungus offer a range of opportunities to replace harmful petrochemical materials and production processes.

- Montalti’s goal is to move beyond the existing production systems into a paradigm that will bring a new landscape of ‘cultivated’ objects into our lives. Like Lee he is also working to scale up production to a viable mass-manufacture level.

- Smaller start-ups such as Algiknit are developing a range of biopolymers with an aim to develop sustainable bio-based alternatives for the textile and apparel industry. This shows that companies at varying levels are working towards a common goal and that the industry is expanding in different directions.

- Adidas have developed a futurecraft biofabric with AMsilk, a fully biodegradable trainer upper. The shoe shows how biofactured materials are now beginning to enter into retail.

- Start-up company Bolt Threads have developed the first bioengineered spider silk tie, currently for sale, made by modified organisms.

- Carole Collet advocates a potential shift to a new paradigm of ‘biofacture’ through her research and design probes that utilise critical design and present the potential of synthetic biology for the future manufacturing of textiles.

- DIYBio and Biohacking offer a collaborative space for exploration, learning and sharing.

- Could the DIY, community, hacking and material activism space be the area to look for methods, values and systems for this new paradigm?

# The Role of Design in a Future Thats Engineered and Grown

## Introduction

This chapter will explore what the role of design could and should be if we enter into a biotechnological age where our materials and products are genetically engineered, biosynthetic, grown and potentially partially alive. It discusses this from a theoretical and contextual viewpoint, theoretically because this future is still unknown, contextually by looking at the work of bioartists and biodesigners who are speculating and discussing this potential future through the use of speculative and critical design. It raises discussion around how design and designers might work in this future, how design education might need to change and gives examples of programmes and competitions already supporting this learning. It discusses the importance of cross disciplinarity between designers, scientists and engineers for such a future and looks at the function critical and speculative design currently takes in this area and whether it could be more research driven. The relevance of this chapter in relation to the overarching aims of the project are exploring whether critical/speculative design approaches can be utilised to research and question the potential of biosynthetic technologies in the textile and apparel industry. This chapter aims to explore the interrelations between design and biology, to consider the opportunities and challenges of these two fields coming together and how our understanding of design and design methods might need to adapt and develop a new framework.

## Biodesign

*"Biodesign is centuries old and at the same time it is of the future."* (Antonelli, 2017) We have been working, designing and tweaking living entities throughout our histories as living beings and in the future we will do this with tools that offer us even more precision. Synthetic biology opens the doors to the design of biology, rather than designing with biology. This could mean a fundamental shift in types of organisms that occupy our planet, their functions and if we use them for production, the things we consume. It is a jump forward from biology being a material we exploit to becoming the hard and software for manufacturing, like computer-programming biology could become a toolbox for designers. As designers it is up to us to consider how we use this new toolbox to support a more sustainable design practice. As Professor Carole Collet states,

> *"It is now time for designers to expand their practice and contribute to imagine this new bio-based regenerative economy to help transition towards a more sustainable future." (Collet, 2017)*

If we are moving into a new paradigm of production, does this mean a new paradigm of design is about to emerge and if so what will this look like? Ginsberg states,

> *"Synthetic Biology's designs on nature require us to adapt our understanding of design, the natural world and life itself." (56)*

We spend so much money on the research, development and making of new technologies and materials but not enough time on studying the effect and consequences that they have on society. Synthetic Biology proposes making things rather than focusing on understanding existing things, the same as many forms of design. The marriage of design and biology requires a review of varying ways we have and continue to learn from and manipulate life and the way in which we make and consume goods. If we start to see biology as a designable and engineerable medium then we start to bring human principles, systems, standards and values into the space of living matter. But what place if any should design have in our relationship to living things? What does design in synthetic biology really mean and what might it involve? How do we design for a world that does not yet exist? And how can we learn from nature in order to tread a different path in the way we design, make and produce things? Pablo Schyfter believes that there is no design in nature, only human's design. Design is shaped by values and design choices and problems are also often shaped by values.

> *"If we think about this in relation to nature, does design exist in nature? Does it make things formed because of particular values? Is it actively aware of designing and care about what and how it designs?" (Schyfter, 91)*

Fundamentally design is motivated by particular needs and desires. Decisions made during a design process come from a set of values, standards and principles. Synthetic biology's claim that it wants to bring "design" to living nature is a concern to Schyfter, as it does not specify what it understands as "design". How can it make sense of what is good and bad design, what does it hope to achieve and why does it want to undertake this project? He believes that a key discussion in this space that is needed is what does design presume, involve and bring about in this field?

Currently design is being subdued into a service industry sometimes detached from its more humane ideals. Has this happened because there is such a detachment of products of culture from the natural world? Our perceived separation of nature and ourselves is a cultural construct in itself. Climate change is a physical example that design and human activity are never independent from nature. If we start to design nature, to shape and control it, to learn from it and make things with it, will our lifestyles, behaviours and interactions with nature and biology change and if so how?

If living things become designed objects, the existing strategies of design will need to be reconsidered. Aesthetics, form, function, obsolescence, things that design has ignored such as life span, circularity and products relationships with nature will need to be examined. Issues with a lack of circularity in design and a mind-set of disposal by consumers could be addressed through a new paradigm of design, one informed by and entwined with biology. Professor Carole Collet writes,

> *"With the emergence of the bioeconomy, design stands a chance to reinvent itself and to influence the shaping of bio-circular production systems that demand a thorough understanding of renewable biodegradable materials and circular supply chains." (Collet, 2017)*

The issues of the textile industry being one of the most polluting on earth and the re-enforcement of a replacement culture with garments being difficult to mend or uneconomical to do so could be challenged. In the future good design may include more long-term thinking rather than problem solving and short-term need. Synthetic biology seems to be fitting into the later at the moment but there is a potential to change this.

Synthetic biologists are keen to make biology predictable and functional, they want to create reliable, predictable, standardised methods for production through the use of engineering design. But the desire for standardisation by synthetic biologists threatens to edit out the complexity and diversity of living things. There is a correlation here to the textile and apparel industry, agriculture and economics. The standardisation of systems edits out the benefits of diverse and complex systems and matter. Collet believes that,

> *"The bioeconomy can only succeed if we alter our consumption behaviours and fundamentally rethink the notion of progress to create a new bio-modernity that is inclusive, interconnected and mindful." (Collet, 2017)*

Ginsberg states that all of the people involved in Synthetic Biology talk about 'design' but that it takes a different form from the design she knows. Some synthetic biologists see themselves as designers, but what is their understanding of design? And should we not first try to understand the existing systems of biology before we enforce our own upon it? Nature and culture, science and society are all interconnected. How do we design for this bigger picture?

## Future Bio-Designers

If we are moving towards this future then designers will need to develop their skills and learn how to use new tools in order to work with this method of living manufacture. This would be a whole new path of education where technology and material become one, where technology no longer transforms an existing material but produces and crafts it. If we think about how digital technology has transformed the industry over the last two decades with the shift to working with digital design tools, living technology will form a whole new set of tools for designers to master.

"The new toolbox is the petri dish; the new programming design software is the DNA code.
Until the late 1990's, the notion of digital design referred to as CAD (Computer Aided Design) and CAM (Computer Aided Manufacture). Could this new emerging bio-digital technologies lead to what I call 'CAB': Computer Aided Biofacture'? So what becomes of the designer in this context? Will our role be to design hybrid bacteria and plants? (Collet, 2012)"

Fashion and textile education would need to adapt to address synthetic biology. This could develop new textile design practices for those willing to engage with engineering living organisms. Future biological designers might be working with design software similar to computer programmers and architects, designing living systems to produce materials.

> *"Future designers of functional living machines – plants, animals microorganisms – will be descendants of plant and animal breeders, genetic engineers, mechanical engineers and scientists, but they will also claim their heritage from design." (45)*

bioCAD is an emerging software market, that would facilitate a drag and drop design of DNA. If this were achievable, how much would a designer need to know about biology? Would a future designer have more in common with a biologist, engineer or designer? Synthetic biologists are not designers in the same sense as those in the creative industries are. Designers operate at a bigger user centric scale, we are generalists, not specialists. We are elastic and design is not a linear path it is messy and exploratory, not clear and defined. We respond to a brief through research and thinking through making, producing unexpected ideas and discoveries along the way. Exploration and the unexpected are encouraged. We crit and review the work and most pieces are open ended developments. Such methods for a scientist may be hard to grasp with their processes being objective and verifiable. This suggests that future synthetic biologists might be versed in bioengineering and human-centred design or that designers and synthetic biologists might collaborate.

> *"As we define our interactions with living things, we will need to develop a design discourse around the cultural function and the design itself of biological products." (Ginsberg, 46)*

MA Material Futures is an example of a postgraduate course at CSM offering the beginnings of this education. The course advertises itself as "a two-year Masters course dedicated to exploring how we will live in the future through trans-disciplinary practice and expert collaboration." (CSM, 2017) It supports students in working at the intersection of craft technology and science to explore future needs, challenges and desires in the 21st century. Part of the course includes a live project with an industry partner; these are often with scientists, designers working with new technology or start-up companies. Students are encouraged to consider current and future contexts within a breadth of areas to create future scenarios and design speculations. Graduates of the course have gone on to work in leading laboratories, research centres and creative start-ups across the globe.

There is also the emergence of design research centres within universities focused on future materials and industry investing in collaborations. The recent announcement of the partnership between CSM and LVMH through a major investment by LVMH to intensify scholarship programmes and fund a ground-breaking sustainability and innovation programme and The Burberry Foundation awarding 3million to the RCA to establish the Burberry Material Futures Research Group, shows a shift in industry investing in research and new collaborations. If we put this into the context of a future where the materials and production methods of the textile and apparel industry have opened their doors to a new portfolio of biomaterials and new production systems, there will potentially be new types of business and brands emerging in this space. Ensuring this space happens in an education environment is essential in order to educate our future biodesigners for the emerging landscape that they will enter into. Whilst tackling key issues within the industry in varying markets.

The Biodesign Challenge is an example of a current competition for art and design students offering the opportunity to envision future applications of biotechnology. Student teams are selected from top design schools in America, but now extended to the UK. The central themes include architecture, water, food, materials, energy, medicine, and others areas where biological design could make a dramatic difference. The organisation provides teams of biologists and experts to guide students as they develop their ideas, along with lecturers from the universities. The projects are presented at a final summit in New York, where the winner is decided. This kind of competition fosters collaboration and sharing of knowledge and expertise. It is creating an essential space where each industry and expertise can learn from one another and foster a space of dialogue, innovation and experimentation.

## The Importance of Trans-disciplinarity and Collaboration

It is evident that collaboration is an essential component to the successful development of a future that is bioengineered, biodesigned and biofactured. Although art and science are not an uncommon marriage today especially thanks to organisations such as the Wellcome Trust, collaborative projects in this field are a small percentage of the creative industries outputs. Designers and scientists working together can be a challenging marriage; there can be difficulties in finding common ground, ways of working and language. The challenge of gaining funding to support a project as lab space and equipment can be expensive, if funding isn't available then finding the time to give around existing responsibilities. There are spaces where this collaboration is happening, often through the support of universities, residency programmes, competitions, awards or researchers.

The iGEM competition is an example, a world wide, synthetic biology event that takes place annually aimed at undergraduate, high school and graduate students. Multidisciplinary teams work all summer to build genetically engineered systems using standard biological parts called BioBricks. The teams work in and outside of the lab, creating sophisticated projects that strive to create a positive contribution to their communities and the world. Aqualose is an example of a project where students from Imperial College collaborated with designer Victoria Geaney from the RCA. The team worked to grow the largest amount of genetically modified bacterial cellulose to show the potential for its production and application. The Imperial team have since set up as CustoMem, a bioengineering start-up developing customisable membranes that target contaminants in water.

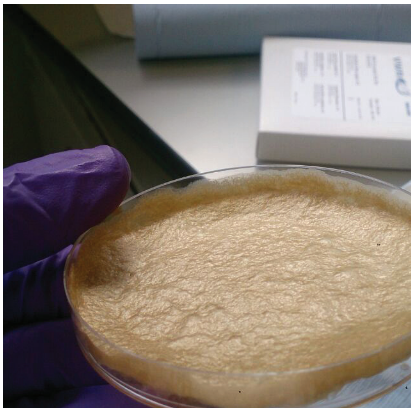


Fig 14.1: Bacterial Cellulose Blended Sample, Aqualose (2014)

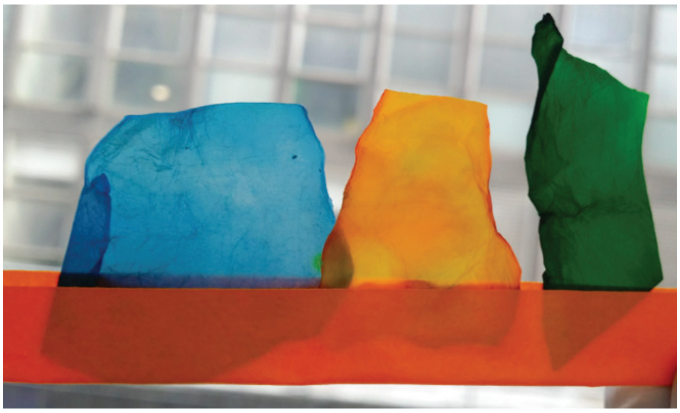


Fig 14.2: Bacterial Cellulose Dyed Sample, Aqualose (2014)

Dr Simon Park is a lecturer in Microbiology and Molecular Biology and Senior Teaching Fellow at the University of Surrey. He also works at the intersection between art and science and has been involved in a number of collaborations with artists and designers. Park founded and curates C-MOULD, collections of microorganisms with interesting properties for use in art and design. His collaboration with Victoria Geaney 'Oscillatoria Sutured' explored the relationship between bacteria and humans through biodesign, suggesting a focus for future fashion and textiles. Materials and designs could be produced sustainably from this material, as it needs little more than sunlight and air to grow. The fibres created from the bacteria and self-weaving and therefore would be self-repairing. The project is an example of a designer and microbiologist collaborating on not only a design problem, but also on a conceptual level by exploring the symbiotic relationships between bacteria and humans. Park's blog 'Exploring the Invisible' is an example of a microbiologist working in a cross-disciplinary manner as he utilises a number of creative skills, from photography to curation and ideas development. The blog is also an example of a space where he is applying his biological skills in a free and exploratory manner, away from constraints of scientific quantitative research methods to qualitative experiments and reflections.

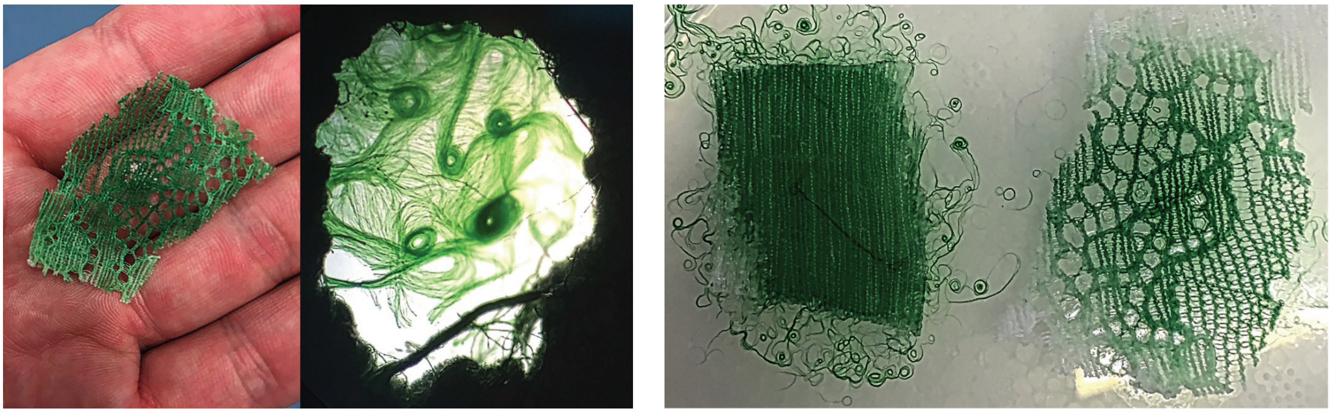


Fig 15.1 & 15.2: Oscillatoria Sutured, Simon Park and Victoria Geaney (2016)

Natsai Audrey is the founder and director of Faber Futures, a London-based Design Futures R&D studio that works with Living Technology and Biodesign. The studio's research journeys are driven by a desire to develop and question resilient systems of manufacturing and design making through the cross roads of life science technologies and design craft processes. Amongst many of Audrey's projects is The Print Room, which is exploring the meeting of design and molecular biology. The project was collaboration with Professor John Ward of The Ward Lab, University College London. The Print Room is the first collection of textiles produced by traditional screen-printing methods using dyes that have been manufactured by bacteria. In this project, they have 'trained' bacteria to produce variable pigments as a by-product of their metabolic activity, by tweaking the composition of their nutrition. Experiments in extraction after this process allow enough pigment to be produced and then screen printed directly onto textiles. This collaboration is another example of a designer and molecular biologist collaborating successfully.

Fig 16: Faber Futures: Fold, Natsai Audrey Chieza (2014)

## Speculative and Critical Design

At present designers and artists exploring the opportunities and challenges of synthetic biology and living technologies are often using critical and speculative design (Dunne & Raby, 2013), which affords methods of future scoping, scenario shaping and debate. Critical design has become an established area of design developed from radical design in the 1970's and promoted by Dunne and Raby during their time at the Royal College of the Arts, London. Critical Design, sometimes termed Design for Debate and Speculative Design utilizes future scoping methods and speculative design scenarios. Dunne and Raby state,

> *"Critical Design uses speculative design proposals to challenge narrow assumptions, preconceptions and givens about the role products play in everyday life. It is more of an attitude than anything else, a position rather than a method." (Dunne & Raby, 2013)*

Although Dunne and Raby state that this is not a design method, in many senses it has become this. Artists and designers working with this form of design are presenting pertinent questions. But some feel that this form of design is simply a method of communication, too fictional in ideas and not starting realistic, feasible debates about the complexities of such an emerging technology. Dunne and Raby's A/B manifesto is however an example of how designers can become philosophical sense-makers rather than just problem solvers, becoming problem-makers. Critical design has the potential to challenge the prevailing attitude that what we make is somehow separate from the natural world.

Artists such as Oron Catt's and Iona Zurr have developed a different form of design that they feel addresses the concerns of designing life more effectively, that of contestable design. Catts and Zurr state that,

> *"The idea of contestable design comes from a position of an experiential, knowledgeable, intimate, nuanced as well as playful place. We develop working prototypes base on the actualities of new scientific knowledge and technological knowhow and use them for cultural discussions; not necessarily celebrating the emerging knowledge and developing technologies but rather culturally scrutinising and articulating in order to make sense of their broader societal and ethical meaning." (Catts & Zurr, 2015)*

The difference is that they are not speculating in the work they create, contestable design is based on new but actual scientific knowledge and technology. They see this as being a platform for cultural scrutiny and discussion and how the living objects and prototypes they create can open discussion about their wider impact and meaning. Design blending into art practice can be used to investigate philosophical and aesthetic issues raised by new materials. This intersection of art, design and biotechnology is where my practice is positioned. I feel that it is important to establish whether critical/speculative design could become a more research-driven form of design. To begin this exploration lets look at some examples of context relevant speculative/critical design.

Ali Schachtschneider's work 'Vivorium' presents a speculative bio-designer who works with biologically grown materials and garments, furniture and tools that become extensions of the body. The project presents speculative scenarios of using lab grown materials such as cellulose, mycelium and tissue cultures. The work is visually intriguing and includes actual grown materials in the form of materials, garments and shoes. But the vision of the future presented here feels too much like science fiction. The tools, colours, performance of the grown garment don't seem to take into about the user. Will people really set up this laboratory kind of scenario and work in this romantic fashion? Of course some people may, but it feels like quite a limited view of such a future scenario and more about the creative process of making the work.


Fig 17.1 & Fig 17.2: Vivorium, Ali Schachtschneider (2015)

Veronica Ranner's work aims to understand and develop what new roles for designers might be at the intersection of emerging (bio)technologies, bio-fabrication, biodesign, systems design, speculative and critical design. Her research looks at the perception and understanding of critical and speculative designs with the aim of fostering constructive criticality of the space between society, design, science and technology. Biophilia – Organ Crafting is an example of this; it explores a future where genetically modified silk worms would weave the scaffold for a donor heart and asks viewers to question whether they would prefer this or machine production?


Fig 18.1 & 18.2: Biophilia: Organ Crafting, Veronica Ranner (2011)

*"Instead of weaving their cocoons, a genetically re-programmed sericulture could weave biodegradable scaffolds for organs, tissues, biosensors and even products — it could shift our understanding of industrial and biotechnological manufacturing from 'hardware' to novel 'wetware'." (Ranner)*

The work aims to offer an alternative scenario to current transplant process, methods and procedures, aftercare and the supply system. It also aims to raise questions around our relationships with nature and how we would view ourselves, if we became a form of interchangeable parts. If silk worms were used to reproduce many different parts of the body how would our connection to them and ourselves change? Ranner's work is a far more realistic and considered vision of the future. This comes from the research led nature of her process and potentially the wider consideration of design, biotechnology and society.

'Biological Atelier' is a speculative and critical design project by Congdon exploring what role textile design will play in the creation of biological products of the future. Congdon is a designer, researcher and lecturer interested in exploring the crossroad between design and science, through an experimental and research driven practice. She often uses speculative design to investigate the implications of engaging with new technologies, such as biotechnology.  She is interested in the use of biomaterials to develop new productions, but also the debate and ramification of these new materials.

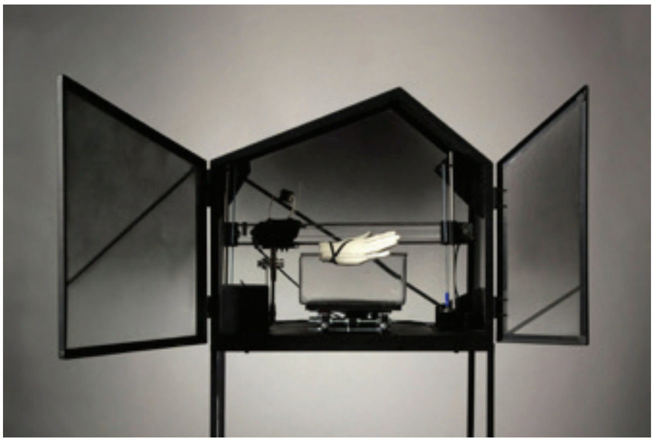
'Biological Atelier' considers the blurring role of the designer, scientist and craftsman in a biotechnological future by imagining a fashion Atelier of 2080. In this period materials are not made but grown, fashioned from cells not fabrics. The project considers how textile skills might be re-appropriated through new technologies in order to facilitate the production of living materials. The outcomes were a series of jewellery, samples and trims that explored the potential of bespoke biological textiles. This series of work focuses a lot on the aesthetics' and the use of photography to present the objects and hypothetical narratives. Parts of the materials in the images have a natural and biological quality, but others are clearly synthetic fabrics and existing matter. Maybe future biosynthetic materials might look like this, but I feel the work is let down by the use of these obvious materials.

Fig 19.1: Biological Atelier: SS 2082 'Extinct' Collection, Amy Congdon (2016)

Fig 19.2: Biological Atelier: AW 2082 'Bio Nouveau' Collection, Amy Congdon (2016)

Congdon's current research is actually putting her into the laboratory space where she is collaborating with tissue engineers at Kings College. Within this research she is looking at how textile techniques can inform new approaches to growing future materials and products, exploring culturing cells over digitally embroidered scaffolds, experimenting with the control and orientation of cell growth. The research aims to grow combinations of cell types on one scaffold in order to create unique hybrids. During this research Congdon is developing a materials and techniques archive. The materials and production methods she is using could have future implications for a number of disciplines such as fashion, medicine or product design. I feel that this avenue of work has more potential for dissemination into critical design pieces, using the primary research and data collected. It could move the work more into the realm of contestable design where conversations about the materials could open cultural discussion around the objects social and ethical implications.

Zuzana Gombosova's work explores the future of textiles; she works with bacterial cellulose exploring new production methods for the use of the material in the fashion and textile industry. As part of her MA project 'Invisible Resources' she developed a '3D Feeder' that could grow the cellulose with a variety of properties, colours, qualities and finishes for use in fashion and product design. Gombosova wanted to raise the questions around how devices can alter perception of products and how the patience required growing material might change our material culture. Though the production of bacterial cellulose is not hypothetical the methods of creating a variety of different properties are. As with many of the graduates of the MA material futures course the work has a futuristic aesthetic in the design and photographic finish. What Gombosova does effectively is push this current technology slightly into the future and in doing this presents a feasible proposition through her considered research. The examples discussed here show the importance of in depth research supporting critical design in order to present feasible and considered outcomes.



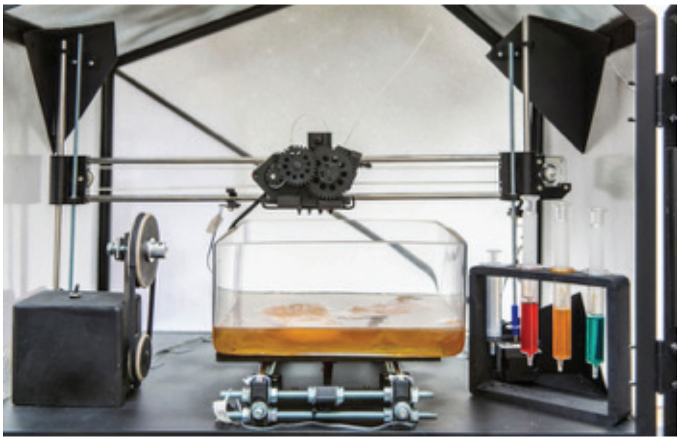


Fig 20.1 & 20.2: Invisible Resources, Zuzana Gombosova (2014)

## From Biomimicry to Biofacture – A Model for Biodesign?

Through her on going research and chapter 'The New Synthetics: Could synthetic biology lead to sustainable textile manufacturing' in the Routledge Handbook of Sustainable fashion, Carole Collet sets out a framework for designing with the living via the lens of sustainability. She proposes a hierarchy revolved around 5 different relationships to nature.

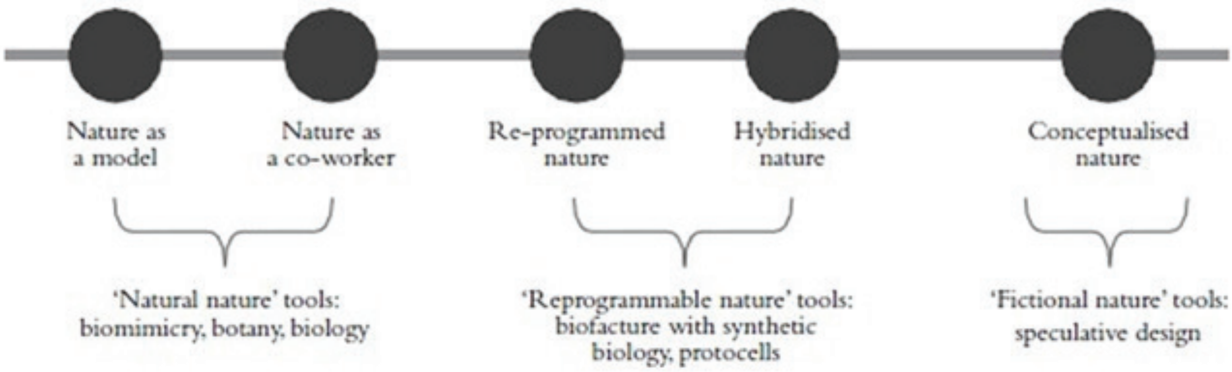



Fig 21: From biomimicry to biofacture: a new hierarchy for designing with the living, Carole Collet (2017)

1. ***'Nature as a Model':*** Designers imitate nature but still rely on conventional production processes. For example, a product such as Velcro is designed to imitate how seed pods (from the burdock plant) hook on to foreign materials, thus providing a means to 'glue' and 'unglue' at will, without the use of chemicals. Yet Velcro is made of polymer-based synthetic fibres, dependent on finite oil resources. 'Nature as a model' is a first step to gain a better understanding of the natural systems and to learn from Mother Nature

2. ***'Nature as a co-worker':*** Proposes the integration of natural biological systems to achieve the production of a material or a structure. An example is the biocouture project, where bacteria naturally produce cellulose, which can then be harvested as a non-woven cellulosic material. The bacterium is a co-worker that needs to be fed and nurtured. Manufacturing becomes like a process of farming.

3. ***'Reprogrammed Nature':*** Is the realm of synthetic biology. This is where new natural organisms can be genetically engineered to produce custom-made materials and synthetic ecosystems. With synthetic biology we can now go beyond imitating the process of nature, we can design biological factories ourselves after a few days in the lab.

4. ***'Hybridised Nature':*** Here, designers may investigate the fusion of nanotechnology with synthetic biology to explore sustainable goals. For example, researchers have now managed to attach gold nano-particles to DNA strands, which could lead to the development of nano-bio electrical living materials. These techniques could be used to develop biodegradable, wearable technologies.

5. ***'Conceptualised Nature':*** Here, designers use speculative design tools to explore and provoke future ideas, as well as to facilitate a much broader public engagement.

(Model taken from Collet, 2016)

Another example of the translation of this model is into the space of curation. ALIVE: New Design Frontiers, curated by Carole Collet for the Espace Foundation EDF in Paris, was a showcase of 'living technology'. The designers involved in the exhibition explored and presented the potential future of everyday products and manufacturing tools being 'alive'. The exhibition explored the following key themes, developed from the 'biomimicry to biofacture' model:

***The 'Plagiarists':*** Designers who mimic nature and use biomimicry principles but rely on conventional manufacturing methods.

***The 'New Artisans':*** Designer-Makers that create new products and materials in collaboration with natural biological materials such as bacteria, fungi and algae.

***The 'Bio-Hackers':*** Designers who work in collaboration with synthetic biologists to redesign and engineer living organisms in order to develop new products and interfaces of the future.

***The 'New Alchemists':*** products and design tools derived from the merging of biology, chemistry, robotics and nanotechnology to create new hybrid organisms, combining living with non living technology.

***The 'Agent Provocateurs':*** Designers that expose and explore the subject to provoke, communicate and debate ethical issues related to living technology and high-tech sustainability.

Collet's framework provides a range of options for designers to engage with designing with the living now and in the future. It effectively suggests the areas and variety of technologies that designers might adopt. As clearly stated this is through the lens of sustainability, could a broader framework open up the potential challenging roles and undesirable roles designers might face being in? Adding to these ideal roles by applying a more critical lens on this potential future of biodesign? In terms of my own practice I sit within the area of 'conceptualised nature', but the narrative within discusses 'nature as co-worker', 'reprogrammed nature' and 'hybridised nature'. Is this framework in need of a redesign where different factors can be interconnected in order to present a more complex model?

## Summary of Key Points

- Synthetic biology opens the doors to the design of biology, rather than designing with biology.
- This could mean a fundamental shift in types of organisms that occupy our planet, their functions and if we use them for production, the things we consume.
- Biology could become a toolbox for designers.
- If we are moving into a new paradigm of production, does this also mean a new paradigm of design is about to emerge and if so what will this look like?

- The marriage of design and biology requires a review of varying ways we have and continue to learn from and manipulate life and the way in which we make and consume goods.
- If we start to see biology as a designable and engineerable medium then we start to bring human principles, systems, standards and values into the space of living matter.
- What place if any should design have in our relationship to living things?
- How can we learn from nature in order to tread a different path in the way we design, make and produce things?
- A key question raised by Schyfter that needs to be answered is what does design presume, involve and bring about in the field of synthetic biology?
- If we start to design nature, to shape and control it, to learn from it and make things with it, will our lifestyles, behaviours and interactions with nature and biology change and if so how?
- If living things become designed objects, the existing strategies of design will need to be reconsidered.
- Issues with a lack of circularity in design and a mind-set of disposal by consumers could be addressed through a new paradigm of design, one informed by and entwined with biology.
- The desire for standardisation by synthetic biologists threatens to edit out the complexity and diversity of living things. This new paradigm of production could offer new systems that are diverse, circular and complex.
- Living technology will form a whole new set of tools and skills for designers to master.
- bioCAD could be an emerging software market.
- Future synthetic biologists might be versed in bioengineering and human-centred design and designers and synthetic biologists might collaborate.

- The Biodesign Challenge, iGem competition and projects between designers and scientists such as Victoria Geaney and Simon Park show that collaboration is already happening.

- Carole Collet's framework for designing with the living via the lens of sustainability 'Biomimicry to biofacture' presents a useful model for designers to work too.

- Design blending into art practice can be used to investigate philosophical and aesthetic issues raised by new materials.

- Critical and speculative design can say a lot, but is the debate recorded effectively and directed back into the work? How can it become more research driven?

# Fashion and Textiles in a Biological Future

## Introduction

This chapter will explore how fashion and textiles as we know them today might change in a biological future. How we might begin to wear semi-living garments, or items that are active by cleaning the air, communicating air pollution, cleaning our bodies or keeping us cool. It discusses how a new aesthetic might emerge if companies and consumers take up biomaterials and what this shift in material, production and product might mean for the industry. It discusses whether a whole new classification and therefore vocabulary might be required and whether new specialist companies and markets might open up. The chapter does this by reviewing a range of artists and designers who are exploring these possibilities at varying levels from feasible propositions to hypothetical speculations in combination with theory. The relevance of this chapter in relation to the overarching aims of the project is to consider specific changes to my industry, the function of garments, terminology, fibre classification and potential future markets. It aims to explore whether biosynthetic technologies could offer sustainable solutions, new materials and circular models, to tackle key industry issues. Posing what could be essential themes for writing the future scenario for my speculative narrative and objects.

## Semi-Living Garments

For hundreds of year's fashion has played a key role for human beings as a vehicle through which to express our identity, status and culture. Generally fashion today is static; it is not seen as being alive or active. Wearable technology embedded into clothing is beginning to change these ideas, but this particular industry is still evolving. How will our understanding of what fashion is and can do and therefore our understanding of ourselves change if we begin to understand that our garments derive from living organisms more clearly? It can be argued that we already wear semi-living garments, wool and silk fibres in particular need certain care in their storage and cleaning and if not looked after show signs of their natural origins in their discolouration, handle and deterioration. But if we move to 'biofacturing' materials and garments that have been made by living cells whether new species, or adaptions of existing bacteria and fungi, how could this shift in production, design, aesthetic and function change fashion? What would these garments look like, do, feel like and therefore what kind of identity would we be projecting? Would people want to wear semi-living garments, or garments made by genetically engineered species? Will our climate be the driver for consumers having to adopt such garments that will give pollution level warnings by changing colour, or protect you from radiation, a bioterrorist attack, or be able to filter C02 into oxygen? Could such garments help to create a greater connection between consumer and nature? Help to encourage us too look after the biome and engage us in a truly circular economy?

> *"Catts and Zurr coined the term "semi-living". If the things we surround ourselves with every day can be both manufactured and living, growing entities, "we will begin to take a more responsible attitude towards our environment and curb our destructive consumerism."*
> *(Paola Anotnelli, NY MOMA senior Design Curator in States of Design 07: Bio-design, Domas Magazine 952 November 2011)*

Victoria Geaney is an example of a fashion designer and researcher at the RCA working with living systems. Geaney's practice explores the intersection of fashion, science, art and technology. She collaborates with biologists and creates work that merges synthetic biology and fashion. The piece below is an example of a dress coated in bioluminescent bacteria that glows for 72 hours. The dress was created through collaboration between Geaney and University of Cambridge academics Anton Kan and Bernardo Pollak. It was created to further research the application of bioluminescent bacteria to fashion and fabric. The piece shows the potential of where the application of specific activities of bacteria could be harnessed and utilised in fashion in the future. Creating hazard wear, garments that express you identity through light and temporary fashion that harnesses biotechnology even becoming a fad like hypercolour t-shirts in the 1990's. But would we ever knowingly wear bacteria as consumers?

Fig 22: Photobacterium Dress, Victoria Geaney, Anton Kan and Bernardo Pollak (2017)

Nancy Tilbury co-founder and director of StudioXO and is driven by the intersection of fashion and technology. Studio XO is a fashion and technology company based in London whose work sits between the physical-digital, the synthetic and the hyper-real. Focused on the role of the body in the 21st Century, Studio XO have a built a state of the art Fashion Laboratory serviced by a team of hybrid experts from fashion designers to coders, engineers to materiologists. 'Skinsucka' is a design provocation set 10-20 years from now exploring our attitudes to consumerism, biotechnology and robotics. As a film its aim is to draw attention to hyper-consumerism and how this can blind us to the exploitation within the fashion industry. The piece is built around a scenario where microbially powered devices eat household dirt, sharing the owner's living space. 'Skinsuckas' clean the home and the skin; they swarm over the body and weave thread from the dirt into clothing, a process of customised manufacture and constant recycling.

The design provocation discusses how the relationship between humans and technology will become more intimate as they evolve to biological living appliances. It aims to make us consider ethical issues about the source of materials and products, the processes used to make them and the impacts of consumption. It also raises questions around whether consumers would embrace such a future.

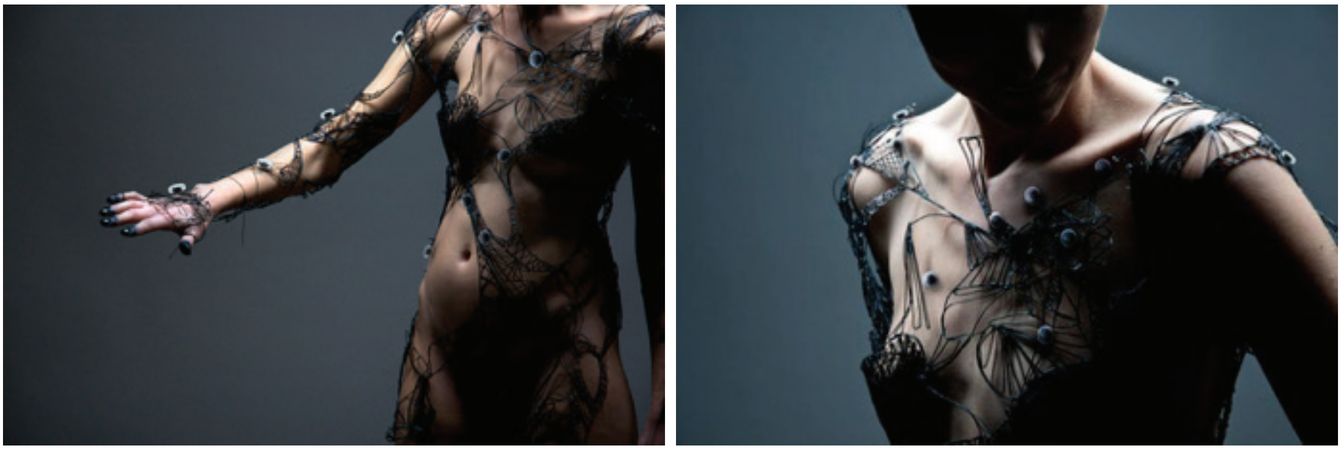


Fig 23.1 & 23.2: Skinsucka, Nancy Tilbury (2012)

Neffa, headed by Aniela Hoitink is a design studio altering and adding properties to textiles in order to propose the way that clothes might act in the future. Studying different living forms and materials she explore growth, nurture and skin and all of its changing, dynamic and living attributes. Hoitnik has created a range of different garments that explore different aspects of her research from e-textiles to a mycelium dress. She see's our skin as the ultimate form of personalisation, creating textiles that react differently based on the wearer. The garment below is made from a material named MycoTex, composed from mycelium; Hoitinik has developed a method of production whether the mycelium is flexible. The dress is produced of a series of these mycelium disks in order to create zero material waste as the piece can be gradually layered and moulded to the desired shape. This construction method also means that the dress can easily be repaired if a section is damaged. The material is fully biodegradable and can therefore be composted at the end of life.

Fig 24.1, 24.2 & 24.3: Mycotex, Neffa (2016)

Would consumers wear a garment made from fungus? And is this material aesthetic something that people would find attractive and want to buy or would it quickly become a fad and trend that passes as quickly as it has started? The potential in terms of sustainable production and disposal is ideal, but is it really feasible as a product and material? The challenges with the works discussed are that the concept its strong, the intention is good and the execution is clear, but the feasibility and consideration to the wearer, market and complex function of fashion seems too hypothetical?

## A New Role for Fashion? - From Passive to Active

SMART textiles have been in the process of research and development for some time now and especially within sportswear we have seen that advancement of stain resistant, thermal controlling, incredibly strong and even scented fabrics. But if we start to produce fabrics that can be engineered biologically, how will the potential outcomes of SMART fabrics develop? Will garments start to take on a role where they can clean the air, warn us of high levels of pollution and even protect us from changing climates? Could garments enter a new phase of not only being a form of identity, decoration and protection to being more active in their function, whether underlying or a key design and functional feature? There is already evidence of such fabrics and garments developed by artists and designers through chemical based dyes.

Nikolas Bentel an American Industrial Designer has developed a series of shirts that communicate when air pollution is at a dangerous level through a series of different patterns. Aerochromics change pattern when they are exposed to air pollution, due to a special aerochromic dye printed onto the shirts. The pattern partially exposes itself at from black to white at 60 AQI (Berlin air quality) and fully at 160 AQI (Beijing air quality). The first shirt has dots that change from black to white when the wearer encounters air pollution. The second reacts to carbon dioxide turning the black stripes to white. And the third shirt reacts to radioactivity. The shirts are currently extremely expensive and offer no resolution to combating air pollution or guide as to what to do when the pollution is at it’s highest. However they do present the potential role that fashion could play in the communication of environmental issues.



Fig 25: Aerochromic’s Collection, Nikolas Bentel (2016)

Helen Storey and Tony Ryan's Catalytic Clothing piece is a collaborative project that developed a dress able to filter pollution from the air. It does this by breaking down air-borne particles into harmless chemicals using a photocatalyst impregnated into the dress. The catalyst is activated by light and can be added to garments during there washing cycle.

Fig 26: Catalytic Clothing, Helen Storey and Tony Ryan (2011)

Although the project is not using bacteria specifically it still highlights the potential shift of fashion beginning to play a more active role in addressing climate issues. Photocatalysts have been incorporated into a number of products from paint to paving stones and cement. If we think about the amount of clothing worn and in the environment around the world, introducing this substance into fashion could have a huge impact.

> *"Exposure to air borne pollutants presents a risk to human health and also has a detrimental effect on ecosystems and vegetation. Air pollution is currently estimated to reduce the life expectancy of every person in the UK by an average of 7-8 months. The widespread introduction of Catalytic Clothing would dramatically reduce the level of air borne pollutants, thereby improving the quality of life for all members of society. The Catalytic Clothing technology won't actively attract any pollutants. Instead, it will break down anything that comes within very close proximity of the photocatalyst's surface." (Dezeen)*

Lauren Bowker is an alchemist who has developed a range of colour changing inks that react to different environments. Some to pollution, others to heat and others to movement. During her time at the RCA she developed the multi award winning PdCl2 ink. The Chromic Dye is capable of reacting to carbon emission, changing from yellow to black. The ink was developed to address the issue of passive smoking but developed to address environmental issues through visual communication.

> *"I graduated with an ink which is respondent to seven different parameters in the environment," Bowker said. "Not only will it absorb air pollution, it will change colour to UV, heat, air friction, moisture and more. This gives it the capability to go through the full RGB scale."*

*"Each ink works very differently, it depends on what sort of material you want to apply it to," (Bowker, Dezeen)*

Fig 27.1: The Unseen Accessory Collection, Lauren Bowker (2017)

Fig 27.2: The Unseen Air, Lauren Bowker (2014)

Bowker also set up The Unseen, a design house based in Somerset House studios focused on developing biological and chemical technology. Again although the dyes that Bowker has created use chemicals, she is also developing biological based technology. The dyes show the potential again for fashion to be active and play a role in communicating its immediate environment and the wearer's health status. I believe that bacteria could be designed to produce such smart dyes and fabrics.

An example where bacteria have been used to develop a SMART material can be seen through the work of Biologic. Developed through collaboration between the MIT media lab and the Royal College of art, the team used bacteria to create a bioskin fabric that opens/peels back in reaction to sweat and humidity. The fabric has been developed from bacteria; discovered 1,000 years ago by a Japanese samurai. The Bacillus Subtilis microorganism has since been used to ferment foods in Japan, including natto – a soybean-based dish. The collaboration between the teams has seen the exploration of these bacteria and its properties in contraction and expansion being applied to textiles that can be used for sportswear. Using an automatic printing system they are assembling fresh cells onto fabrics.



Fig 28: BioLogic, MIT Media Lab (2015)

A team of Penn State researchers have developed a liquid from squid teeth proteins using yeast and bacteria that can fuse fabrics together through heat and pressure. “Fashion designers use natural fibers made of proteins like wool or silk that are expensive and they are not self-healing,” said Penn State Professor Melik C. Demirel. “We were looking for a way to make fabrics self-healing using conventional textiles. So we came up with this coating technology.” (Demirel, 2016) As well as repairing clothes the coating can also incorporate enzymes that could protect workers from hazardous chemicals. The coatings have potential for a range of applications because they are derived from natural sources and therefore biocompatible.

Fig 29: Self-healing film, Demirel Lab/Penn State University (2016)

Though predominately chemical based and therefore currently able to be presented as a prototype, these examples show a potential future that feels more tangible. This appears to be the case because of the visual prototypes available but also because the work is driven and supported by research.

## New Classifications and Industry

Synthetic biology offers the textile industry the potential to both expand and reshape the classification of fibres and fabrics. With its potential to recode existing living matter such as a cotton plant, as well as building life from scratch or reprogramming bacteria to create a cellulose based knitted material it will be possible to programme finishes into the DNA of the living factory right at the beginning of the process. This means that synthetic biology could not only reshape our manufacturing systems but also the classification of materials and textile vocabulary. Professor Carole Collet proposes a textile classification table for 2050 as the following,

*Table 19.1* Textile classification horizon 2050

| | |
|---|---|
| Natural fibres (agriculture) | Vegetal (cotton, linen, hemp, ramie, nettle etc.) and animal (wool, silk etc.) fibres |
| Regenerated fibres (manufacture) | Fibres made from cellulose – plant-based material – (such as wood pulp) and then chemically processed. They include rayon, acetate, viscose |
| Synthetic fibres (manufacture) | Fibres made from petroleum derivatives. They include nylon, acrylic, polyester |
| Synthetic bio-fibres (biofacture) | Any fibre from the previous three categories, but made by genetically engineered living organisms, such as bacteria, yeast, algae and plants. These fibres are usually programmed with enhanced characteristics (such as antibacterial, anti-crease, colour changing, waterproof, fireproof) |
| Synthetic bio-fabrics (biofacture) | Fabrics directly grown into constructed structures by synthetic living organisms, such as bacteria, yeast, algae, plants. These living organisms are programmed to produce knitted, woven or non-woven structures. They can also grow fabrics with smart characteristics and behaviours, such as shape-change or climate-control fabrics |

Source: ©Carole Collet 2013

Fig 30: Textile Classification Horizon 2050, Carole Collet (2013)

The table proposes that both bio-fibres and bio-fabrics could become new textile classifications by 2050. Synthetic ‘biofibres’ could be made by genetically engineering organisms to produce existing natural and man-made fibres. These fibres could be programmed with particular characteristics and enhancements such as anti-crease, anti-bacterial, waterproof, flame retardant and could even change shape and colour. They would be constructed through existing methods into fabric, whether woven, knitted or non-woven (Collet, 2013). Synthetic ‘biofabrics’ could be made by the same living organisms but directly grown into constructed fabrics. Synthetic cells would be programmed to produce knitted, woven and non-woven fabrics, structures and even fully constructed garments. These fabrics could also be programmed with characteristics and enhancements as with the ‘biofibres’, but they may also include smart characteristics such as climate-control and shaping changing behaviours (Collet, 2013). Synthetic biology could help the industry bypass certain production processes, which in turn could offer much greener methods through the reduction of water use, energy, toxic waste water and cheap labour.

Taking these new fibres and fabrics into the next step of the lifecycle, brands and manufacturers would have a whole new portfolio of materials and processes opened up to them. This could offer new methods of production at a range of varying market levels and more specific design and manufacturing options dependent on the market level, brand and requirements. For example in terms of bespoke and couture production, it could offer the opportunity for the brand to design and own the patent for specific genetically engineered materials or even species. Species that would produce materials of a certain colour, pattern and fibre, bespoke to their brand. As collet states, “What would a bacterium working for Chanel produce? What would yeast designed by Marc Jacobs do? What if Dolce and Gabbana we to employ plants to spin lace? (2016: 194)” The fashion and textile industry would be engaged in a very different landscape where ‘Biodesign’ would be integrated into fashion and textile design and production.

In terms of fast fashion and high street brands in the textile an apparel industry, the speed of production could be met whilst reducing the impact on the environment, labour and energy sources. It could offer garments that would only be worn a handful of times and then composted, creating a circular system that utilises materials relevant for their purpose, lifecycle and lifespan. If we can programme biology to make materials, there is potential to take control of the entire lifecycle (Ginsberg, 2014). For industry, synthetic biology could offer the opportunity to develop models that integrate material, energy, manufacturing, assembly and disposal. Waste could be biodegradable or remanufactured for the next set of products as closed material loops advocated by the Circular Economy (CE) (Ellen MacArthur Foundation, 2013). Would this simply feed the relentless pace of the fast fashion industry however rather than solving its issues of speed, waste and shameful labour practices?

What would these new materials mean for the fakes and counterfeit market, would it help to reduce the existence of this industry or would it expand the market even further and into darker realms of DIY Biohacking? Would a black-market of recoding DNA in existing species and unregulated production of new living species emerge to produce cheaper versions of these ‘Biobespoke’ products? How would the Bioindustry control this and could it damage the Bioeconomy’s development?

‘Circular Biodesign’ (Figure 31) is a model presented as part of a research paper delivered at the centre for sustainable designs annual Sustainable Innovation Conference 2016. The model proposes a future circular, self-contained, biological system for these ‘biofibres’ and ‘biofabrics’ suggested by collet.

Informed by circular economy principles and models (Ellen MacArthur Foundation, Goldsworthy et al) it applies systems thinking to propose a future model for the textile and apparel industry.

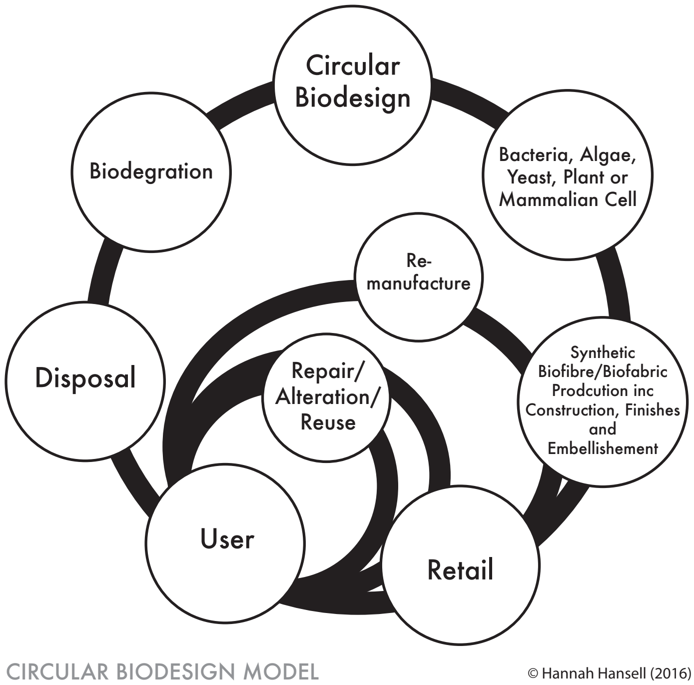
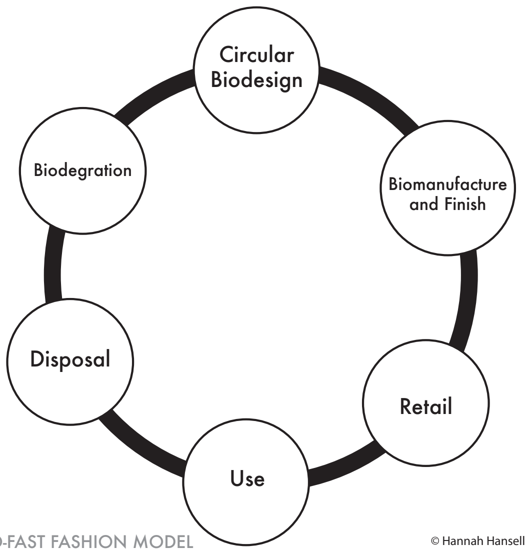



Fig 31.1: Circular Biodesign Model, Hannah Hansell (2016)

The design of the model is based on the potential of synthetic biology to create closed product loops. Manufacturing materials with synthetic cells could offer greener methods of production through the reduction of water use, energy, toxic chemicals and the biological make-up of the products. The technology uses the potential to recode existing living matter such as a cotton plant, as well as building life from scratch or reprogramming bacteria to create a material. Programming finishes, lifespan, embellishment, fabric construction and properties into the DNA of the living factory right at the beginning of the process. In this system apparel can be manufactured from fibre to finished garment complete with embellishment, finishes and smart characteristics all in one location and production process. Every design detail could be programmed into a cell, just like a computer at the very first stage of the products lifecycle.



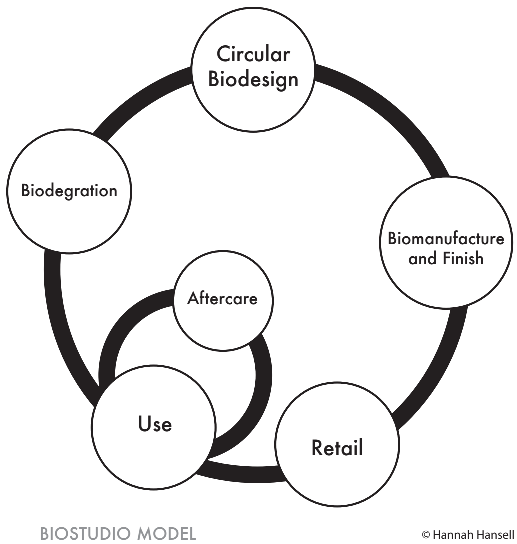




Fig 31.2: Bio Fast Fashion Model, Hannah Hansell (2016)

Fig 31.3: Bio Studio Model, Hannah Hansell (2016)

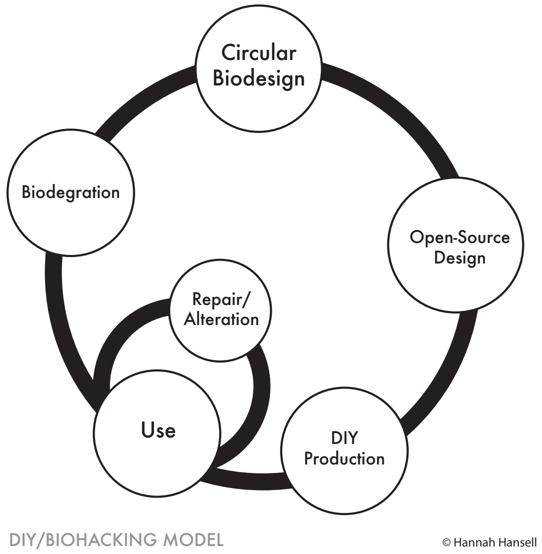



Fig 31.4: DIY/Biohacking Fashion Model,
Hannah Hansell (2016)

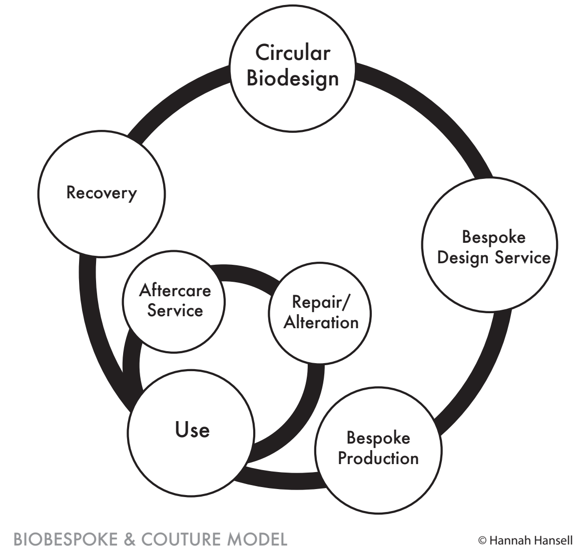



Fig 31.5: Biobespoke and Couture Model,
Hannah Hansell (2016)

The Bio-Fast Fashion Model (Figure 4) proposes a circular system that would utilise the biodegradation of biological materials as a remedy to the speed of the industry. Apparel and textiles could be worn and used a limited number of times and then composted back into the biome. This process of manufacture allows the speed of the cycle within fast fashion to be maintained whilst offering more sustainable solutions to material waste. The Biostudio Model (Figure 5) works in a similar manner but considers an additional loop in the cycle and a slower speed of consumption. At this market level of high-end high street fashion, consumers would be buying items that are used for a longer period and therefore would be repairable and cleanable. This market level would offer in store advice, advanced care labels and would open up a market to new cleaning systems for biological products.

The DIY/Biohacking Model (Figure 6) works in a different manner where the design process would be supported by open-source information for the design and manufacture of products. This would also apply to the fakes and counterfeit market. A black-market of recoding DNA in existing species and unregulated production of new living species could emerge to produce cheaper versions of these ‘Biobespoke’ products. The Biobespoke & Couture Model (Figure 7) proposes that fashion houses and brands could own the patent for specific genetically engineered materials or even species. Species that would produce materials of a certain colour, pattern and fibre, bespoke to their brand. These bespoke fibres and fabrics would enable an even greater personalised design service. The model also proposes the addition of an aftercare and alteration service and recovery of the product back to the company to ensure that bespoke materials and products value is not reduced.

## Bioretail and Biocare

Synthetic Biology could give us new ways to purchase, use and define textiles and apparel. Our current retail experiences are defined by a linear economy that once a garment is purchased it is in the hands of the consumer to look after. Based on the previous models Bioapparel could shape a different retail experience at certain market levels where consumers might co-design and seek aftercare advice. Fashion retail might become more of a hybrid between production studio, merchandising space and repair and alteration service. Disposal of biotextiles and bioapparel could then be as simple as putting your used clothing into your compost bin in the garden, or returning couture pieces to the brand for recovery.

Such new biological materials will require new cleaning and aftercare practices. This will open an opportunity for the development of new types of washing machines, repair services and products. Cleaning such fabrics and textiles could offer much more environmentally friendly practices, where machines include nutrients, feedstocks and microbes that can be reused, reducing or even eliminating the use of water and pollution through cleaning products (Lee, 2012). If not it could develop a new aesthetic that would enable greater connection and emotional durability to products if the wear and tear were visible on the surface over time, like aged leather. Though we have a desire to design things to stay the same, clothing falls apart and decays over time. What if we began to use entropy as a design feature in biological products? If we can see the aging and wearing process of products as something positive and a natural process, we could also think about their changing stages could be useful. Designing with change as part of the products lifecycle is an interesting concept for designers. Instead of trying to keep products in a stasis, untouched by time and wear it could be used as a design aesthetic.

Textiles and apparel produced by living cells have the opportunity to make the already existing link between textiles and living systems more visible for consumers by enabling them to think about materials as living dynamic systems. This industry could create fabrics and garments that look exactly the same as current products, but it could also create new materials with a biological aesthetic. At either end of this scale the question is whether consumers will adopt such living, genetically engineered garments.

## Summary of Key Points

- How will our understanding of what fashion is and therefore our understanding of ourselves change in a biological future?

- If we move to ‘biofacturing’ materials and garments made by living cells, how will this shift in production, design, aesthetic and function change fashion?

- What would such garments look like, do, feel like and what kind of identity would be projecting?

- Would people want to wear semi-living garments, or garments made by genetically engineered species?

- Will our climate be the driver for consumers having to adopt such garments that will give pollution level warnings by changing colour, or protect you from radiation, a bioterrorist attack, or be able to filter C02 into oxygen?

- Could such garments help to create a greater connection between consumer and nature? Help to encourage us too look after the biome and engage us in a truly circular economy?

- ‘Skinsucka’ is an example of a design provocation that effectively discusses how the relationship between humans and technology will become more intimate as they evolve to biological living appliances.

- If we start to produce fabrics that can be engineered biologically, how will the potential outcomes of SMART fabrics develop?

- Chemical based dyes and treatments have been developed to create SMART fabrics by designers, but industry has not put these into mainstream garments due to cost and/or impact on existing aftercare industries. Will this resistance continue with biological products?

- R&D at key universities is producing early stage possibilities for SMART biological materials.

- Fabrics and garments that look exactly the same as current products can be created in this merging industry, but we could also create new materials with a biological aesthetic. Using entropy as a design feature in biological products could help consumers to make a connection to nature and the source of products.

- Synthetic biology could not only reshape our manufacturing systems but also the classification of materials and textile vocabulary.

- Varying levels of industry could take on these new materials and methods of production in different ways.

- Bespoke and couture production could offer the opportunity to design and own the patent for specific genetically engineered materials or even species.

- Would a black-market of recoding DNA in existing species and unregulated production of new living species emerge to produce cheaper versions of these ‘Biobespoke’ products?

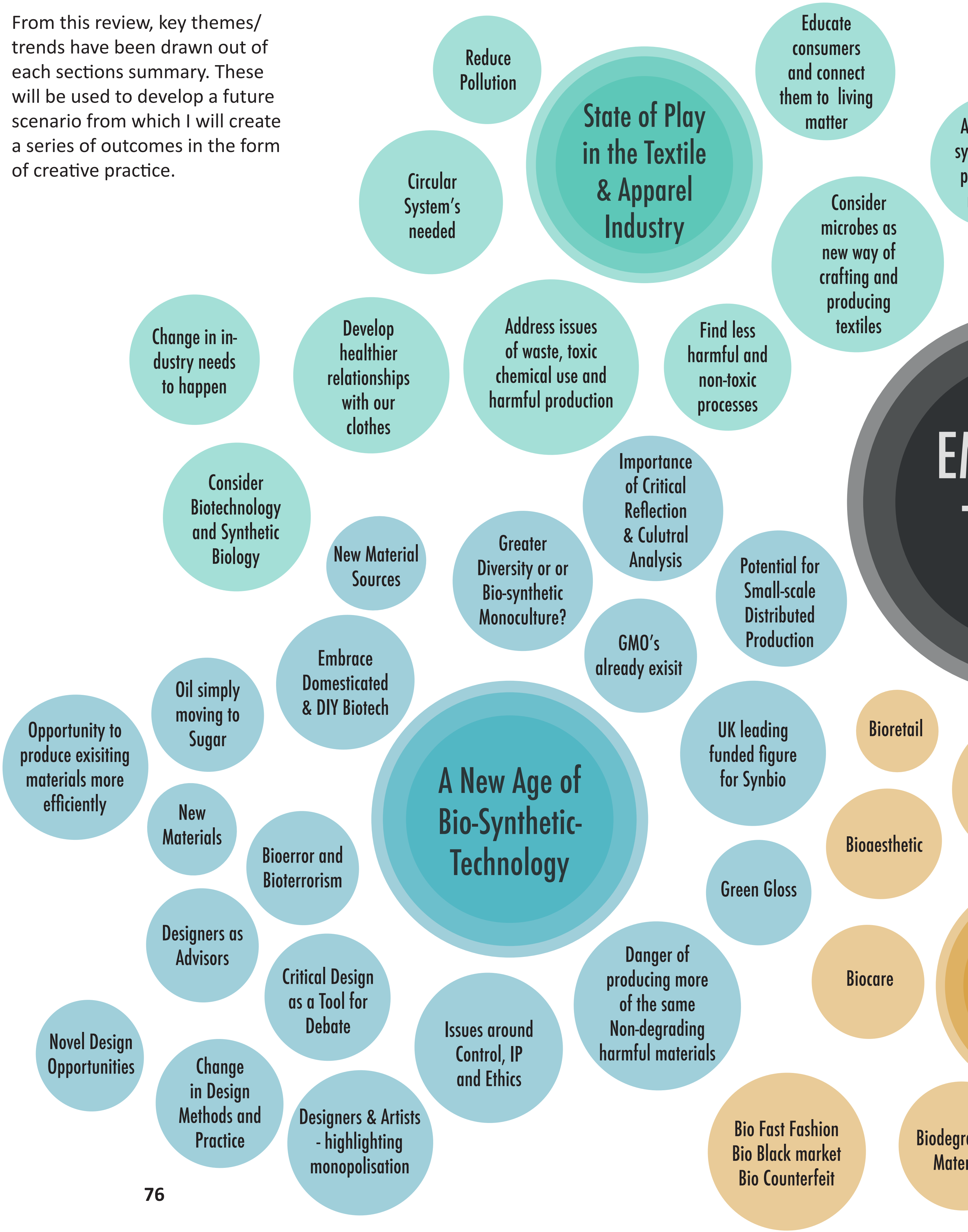
- Bioapparel could shape a different retail experience at certain market levels where consumers might co-design and seek aftercare advice.

- Disposal of biotextiles/bioapparel could be as simple as putting used clothing into a compost bin in the garden, or returning couture pieces to the brand for recovery.

- New biological materials will require new cleaning and aftercare practices. This will open an opportunity for the development of new types of washing machines, repair services and products.

# Emerging Themes

From this review, key themes/ trends have been drawn out of each sections summary. These will be used to develop a future scenario from which I will create a series of outcomes in the form of creative practice.




Biomaterials = new production methods, design, aftercare and aesthetics
New paradigm of production
Materials Revolution
Bio-innovation seen at bio focused conferences
Microbes becoming factories of the future
Biofactured materials now entering industry
A New Paradigm of Production: Factories of the Future
dopt new stems and roduction methods
Emerging intra-disciplinary and cross-sector companies
Growth & Cultivation
DIYbio
Biohacking
Biofacture
Potential to create bio-based alternatives for F&T industry
Potential shift in the way clothes are manufactured and cared for
Values could be taken from Biohacking, DIY and Community Bio
MERGING THEMES
Framework for Designing with the Living
Design of Biology
New products
Values, principles and standards entering the liliving world
Learning from living organisms and design practices
Biology - Toolbox for Designers
Opportunity for Research Driven Critical Design
SMART Biofabrics
New Organisms
The Role of Design in a Future that's Grown
Lifestyle and Behaviour Change?
New Classifica-tions
Greater Nature Connection
What will biofashion look like?
New set of Tools and Skills for Designers
Fashion and Textiles in a Biological Future
What is design in Synthetic Biology?
New Paradigm of Design
Biomarket and Industry
Need for Collaboration
Design and Art Practice Blending
New Vocabulary
Will our relationship to nature change?
Diverse, Circular and Complex Systems
adable rials
Semi-living Garments
Biobespoke
BioCAD

# 03: Methodology

## Methodology

The epistemology of my research is within the paradigm of constructivism. As a constructivist I believe that there is no single reality or truth, and therefore reality needs to be interpreted. That individuals construct their own realities and beliefs to make individual and social meaning out of what they subjectively experience (Guba & Lincoln, 1985). It is important to note that my area of research also fits into the positivist paradigm as a developing scientific field. However I will approach this project within the constructivist paradigm due to the fact that my research context is design and the textile and apparel industry. As a researcher in the constructivist paradigm I will use qualitative research methods to gain data from multiple realities.

My research strategy is exploratory and iterative as I am making work that speculates what the future of the textile and apparel industry could be if we move into a bio-synthetic-technological era. It is also intra-disciplinary, as it brings together a range of disciplines.

## Methods

Within this project I will use 3 qualitative research methods, creative practice, focus groups and interviews. As a research method I am referring to creative practice as both practice-led research and research-led practice. I see the work of art as a form of research and the creation of work as a generator of research insights, which are documented, generalised and theorised (Smith & Dean, 2009). It is important to mention that the focus groups and interviews will not be conducted until the time of exhibiting the work; therefore the data and conclusions will not be available in this workbook due to the submission deadline.

### Creative Practice

I have chosen creative practice as my main research method because it offers the opportunity for iteration, testing and experimentation. I will be using a combination of fashion and textile skills, digital photography, film and model making to create speculative narratives and objects informed by research. It is important to note that creative practice will be both a research method and outcome.

Examples of my practice include growing bacterial fabric and constructing speculative samples and photographic scenes (examples below). Initial pieces will be maquettes and tests, which will be used in focus groups to gain data on reactions and perceptions of the material and object narratives. During the process I will use a sketchbook to develop ideas, designs and drawings. I will keep a sample box of grown materials and experiments in construction, embellishment and finishing of the materials. I will also record the process and experiments through photography, notation and writing, which will be documented, in a workbook. This will be used to inform my MA final show work.


Fig 32: MA Works, Hannah Hansell (2016/17)

The strengths of using creative practice as a method of research are its exploratory, iterative nature. Creating Scenarios and narrative through a series of mediums enables me to propose future narratives and test them in the world today in order to gain peoples reactions. Creative practice also allows me to reflect in and on-action (Schön, 1984) and record data through sketchbooks, a reflective journal and a photo diary. The weaknesses or challenges of using creative practice is that it is a comparatively new field of research and therefore methods of research are still in the process of development. It can therefore be a challenge to define and justify the processes. I need to ensure that I record the data accurately otherwise this could pose issues around the validity of the research.

## Focus Groups
I have chosen this method because I want to collect qualitative data from a specific group and appropriate target market. I intend to use focus groups as a way to gain feedback from designers, design educators and design students during and after the exhibition. This will be a series of sessions where I present the final outcomes. The aim of this is to gain feedback to support reflection in and on-action (Schön, 1984) and to help inform future creative practice outputs.

The strengths of using this method are selecting a small group of specific people will enable me to gain a detailed set of data. I can select a group of people who fit the demographic of my desired audience for the research in order to gain insight into reactions and debate around the work. The weaknesses of such a method are that the data could be too focused and not enable a wide perspective to be recorded. Focus groups can take time to arrange and often participants might have to drop out at the last minute due to other commitments. Working in a University however I have the advantage of having access to specific groups of students and peers, therefore I do not envisage this being a problem. I have already spoken to key members of staff about specific student groups and workshops.

### Interviews
In relation to this project I have selected this method because I want to gain data and insight into peoples attitudes towards the potential future that I will be creating. To see how people feel about such changes to their clothing, products and retail experiences.

The strengths of using this method are that questions can be carefully formulated prior to the interview. Once you have someone agreeing to the interview there is potential to direct the questions by interpreting what the interviewee is engaged with through facial expressions and body language. The weaknesses of using this method would be that in an exhibition setting not all visitors would want to engage in an interview. I would be asking members of the public for consent on the spot, which takes time away from interviewing. As the interview would be face to face the interviewee might be worried about offending me and therefore not give a completely honest answer about the work. This could affect the type of data that I will gain. As a way to remedy this issue our final exhibition will be shown for 2 weeks, this should allow me time to gain a broader spectrum of interviewee's and data.

## Data Analysis

Within this research project I will be using inductive reasoning for my analysis, with a process that will be exploratory, creative and iterative (Patton, 2002). Theories will be developed from the data in a 'bottom up' process. My choice of an inductive method is due to the fact that I will be using qualitative research methods and engaging in a combination of practice-led research and research-led practice.

Analysis will be a cyclical process, as data will be collected at different points in the project. There will be two cycles of research and development and collection of data. Creative practice being an ongoing process of data collection and analysis and the focus groups and interviews being conducted during and post exhibition will analyse how effective initial creative outcomes are in order to inform further development of work.

I will create transcripts of the focus groups and interviews, which will also be inductively analysed. As some data analysis will come from the interview conducted during the final exhibition as mentioned the final analysis will come after my summative assessment point. The use of this collection of processes will allow the data from my creative practice and focus groups to be examined from different perspectives until a point of 'saturation' is achieved (Crouch & Pearce, 2012). The selection of these 3 methods also aims to create a 'triangulation' (Gray & Malins, 2004) in order to understand the data from different perspectives.

The data will be coded into themes and topics and refined down using the 'table method'. I will use the process of filtering, mapping/grouping and then Interrogation as suggested by Gray & Malins (2004: 141-2). I will also use the sieves and spectacles method (Gray & Malins, 2004) in order to distil the data in different ways. These processes will allow a reduction of the data and then methods of display and drawing conclusions will be applied. The aims of this analysis are to develop a synthesis and interpretation by going beyond the data (Gray & Malins, 2004). Finally I will critically evaluate and discuss the research limitations as part of my analysis. For this submission I will only be able to complete this analysis and draw conclusions from the creative practice data.

## Research Ethics

The University of Brighton (UofB) requires a Tier 1 checklist to be completed because I will engage participants in this project. Due to the nature of my research methods and participant type I will not need to complete a Tier 2 application as I will not be engaging vulnerable adults or children.

Following guides of good practice in research set out by the University participant consent forms will be completed by those taking part in the focus groups and interviews. A participation information sheet will be made available, and a verbal explanation of the study given. Consent forms are required as the focus groups and interviews will need to be recorded via photography and audio to ensure accurate data capture. Participants will also be made aware that they may withdraw themselves from the study at any time, and no personal information will be disclosed at any point during or after the research project.

It is also important to note the complexities of ethics in the subject area I am dealing with. Genetic modification (GM) and synthetic biology raise a number of issues in regard to bioethics. It is important to clarify that I will not be working with any GM organisms or materials. And to acknowledge that if the project was taken further into Doctoral study, that the research ethics would be much more complex. However with the timescale of this study, level of research and lack of collaborative engagement with a lab or microbiologist the ethics remain at a low level of risk.

# 04: BIOmatters

## Scenario

It is not possible to predict the exact changes that will take place to the textile and apparel industry over the next 30+ years, but we can be fairly sure that it is unlikely to look exactly as it does today. As stated in the Forum for the Futures, Fashion Futures 2025 report, we have seen the fashion industry become faster and more globalised over the last 20 years. The use of the Internet, mobile technologies and greater connection to information has seen raised awareness in workers pay and conditions, the availability of clothing and retail moving into the digital space. Global changes that impact fashion such as resource availability and prices, climate change, political shifts and energy sources. Following on from the context setting provided by the review this scenario sets out the wider landscape, climate and position of the world leading up to 2050. The review does discuss these wider contexts but is position more within the present day; therefore this scenario aims to set a foundation for the potential future that the narratives would exist in.

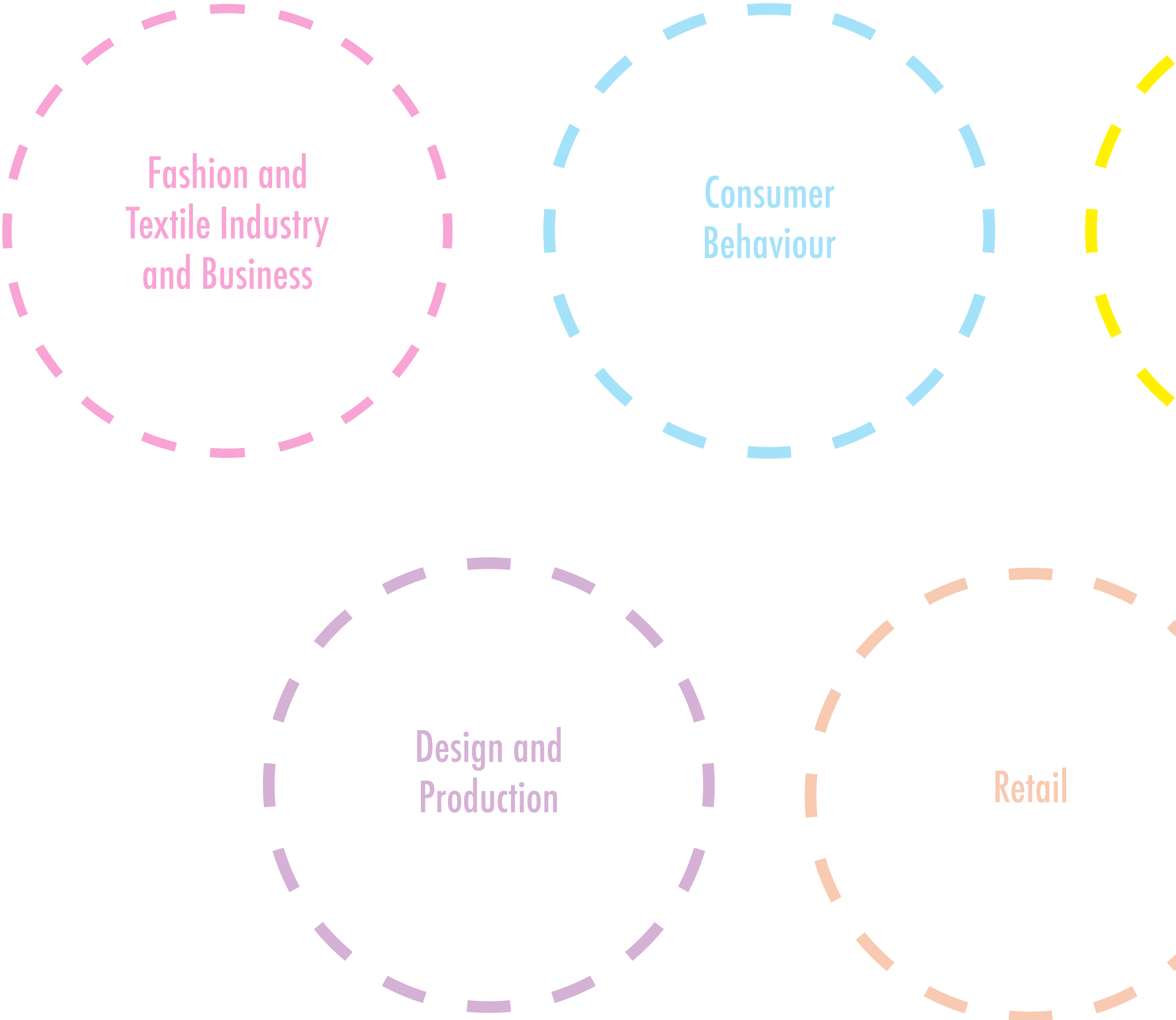
It also takes inspiration from the way that the key trends are written and set out by the forum for the future in their Fashion Futures 2025 report. Forum for the future gain their research from a range of industry experts, this particular report interviewed 40 experts and involved desk based research developing 170 key trends. These were developed into 4 key scenarios, as the most relevant model I have adapted this structure to shape my own scenario. I have only developed 1 scenario, as the narrative is a range of interconnected stories. It is important to reiterate that this scenario is not a prediction but an image of a possible future within the context of my study. It has been created to provide a framework to propose and design within, to highlight challenges and opportunities and to test critical/speculative design narratives and artworks.

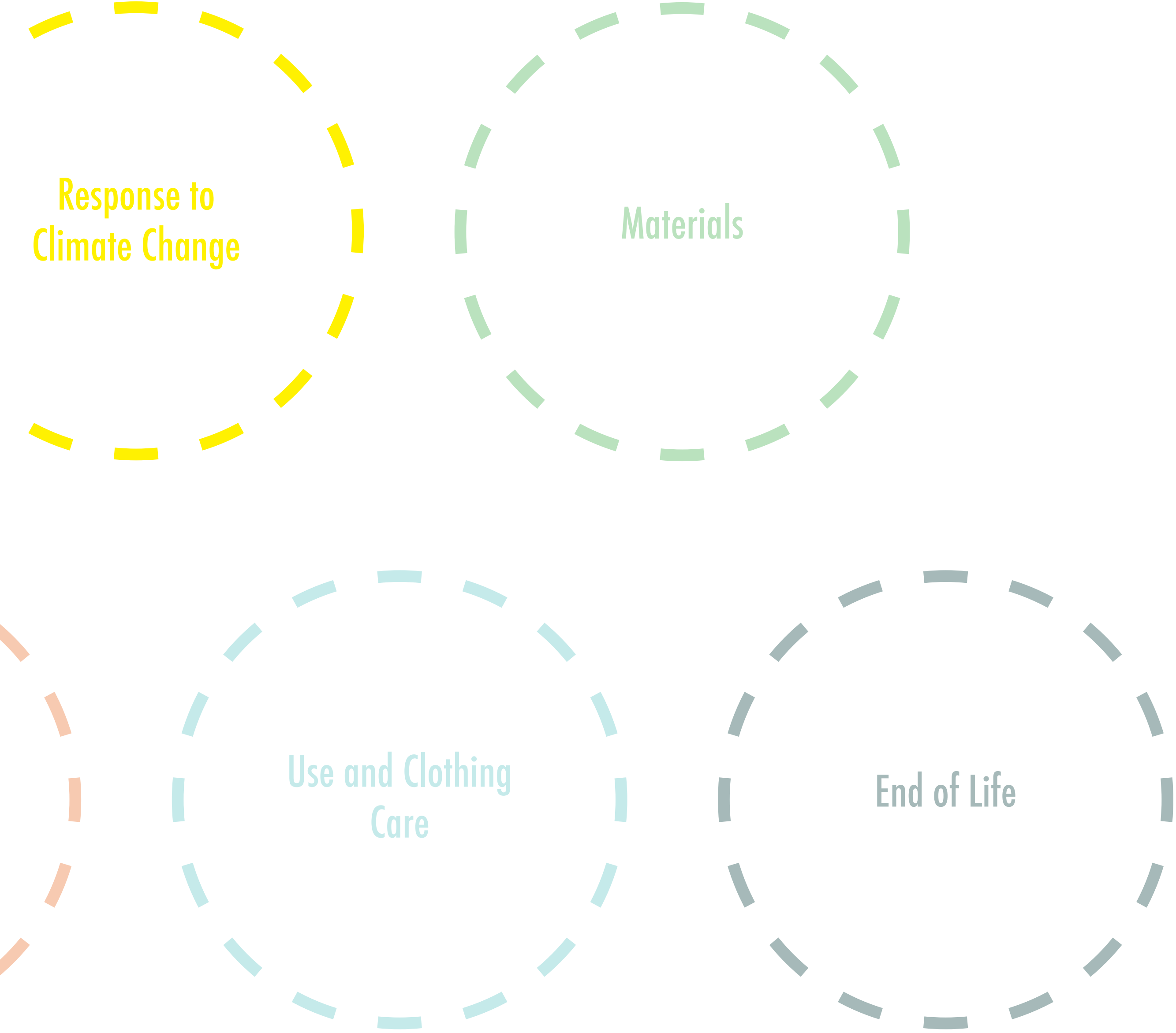
# Summary of the Scenario

The world has moved into a new industrial era, a biological age where products and materials are designed and grown by biological organisms. The 'Biotechnological Revolution' of the 2030's saw the design or redesign of biology and a new material age and production paradigm focused on cultivation, growth and bioengineering take shape. Reprogrammed microbes have become our factories and production has seen a shift from hand and man-made to grow-made. Organisms such as bacteria, yeast, fungi, algae and mammalian cells are genetically modified or rebuilt from scratch to create materials with new aesthetics, properties and are claiming to create more sustainable products. A new classification of materials has opened up for use by designers and manufacturers, which have created new systems of production, know as biofacturing.

Large investment in research and development for biotechnologies in the area of biomaterials and synthetic biology for application into the textile and apparel industry in the 2020's supported this industrial shift. Developing from successes in medicine in the early part of the century, a reduction in cost for this type of production helped the technology to be adopted by industry. Utilising the practices and systems of biotechnology, biodesign and biofabrication to create materials, products and production systems from living cells companies within the fashion and textile industry have adopted frameworks for designing with the living from biomimicry through to synthetic biology. Society has adopted this new aesthetic and is now wearing biosynthetic semi-living garments and accessories.

# Areas of Focus




Response to Climate Change
Materials
Use and Clothing Care
End of Life

## Fashion and Textile Industry and Business

As the main source for material production has shifted from oil and cotton to sugar, the feedstock for biomaterials, countries such as Brazil, India and China have profited from the switch in global crop demand. This is however causing a similar problem as oil originally did with land ownership being largely monopolised, controlled and a bargaining chip in more corrupt countries.

China is no longer the clothing factory for the world, though it does still play a large role in this industry. The job market in Asia has taken a big shift into care for the elderly population. Alongside this there has been a shift in industry and manufacturing processes to biotechnology. Therefore many workers have needed to switch industries or re-train.

With a whole new portfolio of biofibres and biofabrics opened up to textile and apparel brands and manufacturers have adopted new 'bioranges' or completely new SME businesses have started to emerge. A number of these brands products are classified within the area of biobespoke garments. Many high end high street and luxury brands have adapted their promotion and marketing to attract consumers looking for bespoke, customised and sustainable alternatives to synthetic fibres, fast fashion and unsustainable apparel. As well as selling this more environmentally conscious lifestyle they are also rated through the transparency and sustainability of their business model. Consumers in this area of the marker want more from brands, through assurance of what they are buying into.

## Response to Climate Change

What felt like a long term of president Trump that ended in the mid 2020's took its toll on climate change action and the reduction of carbon and global temperatures. Climate change deniers were few and far between however and after his term ended we saw the Paris climate agreement being signed by all countries. Alongside this there has been a shift in the raw materials and production processes used within in industry. In textiles and apparel the use of new biofacturing systems and grow-made methods has seen a huge reduction in the use of water, energy and harmful chemicals. This new industrial age has focused its attention of circularity, sustainability and looking to nature rather than simply taking from it.

The change in manufacturing areas moving from centralised big business to smaller distributed manufacture is also having positive benefits on the reduction of carbon emissions in the transport of textiles and apparel. This has been further reduced by the combination of retail, design studio and repair shop in many business models.

## Consumer Behaviour

Consumer purchasing habits have predominantly shifted to online shopping, but bespoke and luxury garments still offer retail and studio based services. This is mainly due to the cost of such services including a tailored and personalised service. Customisation has become a key trend for consumers, often searching for the most biologically individualised garment or accessory.

Due to the cost of the biobespoke garments there has been a rise in fakes and counterfeits being sold on the blackmarket. It is clear that consumers desire for these new products overrides their morals and values as many of these garments have been causing harm to the micro biome.

The level of consumption with the introduction of biogarments has evened out as garments are either designed for longevity, return to the brand or biodegration. The industry is managing to address fashion speeds through the composition of the materials and production methods.

## Materials

The search for new sources of raw materials after the decline of oil and petrochemical based synthetic materials took precedent from 2030 onwards. This in combination with the decline in cotton production caused by climate change spurred the shift into a new material age. A new classification of materials for use in the textile and apparel industry was required to fill the resource gap, developments in biotechnology and biomaterials filled this hole. As a portfolio we have seen replacements for depleted stocks of petrochemical man-made fibres and cotton come into the market along with completely new innovative fabrics. Biotextiles are grown from cross species engineering, to genetic modification and completely synthetic microbes.

Materials like Biosilk have been on the market for 30 years now. From this we have seen the development of synthetic leather from Modern Meadow to Synthetic Spider silk, mycelium fabric from mycoworks to a new form of bacterial denim. To SMART biotextiles that can communicate air pollution, convert carbon into oxygen and that can grown, dye and embellish themselves all in one production process.

Biomimicry has also inspired the development of textiles that can adapt to different environments heating and cooling themselves. Using nanotechnology to create different SMART properties through Nano construction rather than chemical finish.

## Design and Production

Biodesign and Biofabrication have become key new processes for the design and manufacture of the new classification of synthetic and non-synthetic biomaterials. Designers have had to reskill in areas of bioCAD, nano design and gene editing.

Co-design has also become popular in line with trends around biocustomisation to encourage a greater connection between products and consumers. This has emerged in the luxury and bespoke markets more than anywhere else due to the cost of such customisation. However the rise of DIYbio and open source has seen personal production and customisation develop.

There has been a rise in small-scale distributed manufacture in the area of biotextiles. With materials and garments being produced by living cells the scale of production has changed due to the condensation of many processes. There have however been a number of protests and riots from workers in Asia due to reduction of jobs and reskilling requirements. Distributed manufacture has seen a shift from large corporations to more specialist manufacturers and in-house production by brands. This has also supported the adoption of circular models from existing industry.

## Retail

Fashion retail has predominantly moved online through technological innovation and a hyper-connected world. Trends of instant gratification, borrowing and customisation in the early part of the century, has shifted to a desire for greater connection to garments, new materials and biocustomisation by consumers. Because of this there has been a shift in the format and function of retail spaces becoming combined shop, design studio and manufacturing space. Here customers can browse, co-design and see the process of grow-making. There are also services for repairing and cleaning biogarments in these retail spaces.

We have begun to see grow-made apparel and biofactured clothing come on to the market at varying levels from high-end luxury and biobespoke to high street and emerging second hand markets. Brands are focused on selling a lifestyle and within this section of the industry these products are being sold as a low-carbon, sustainable lifestyle and mind-set. The circular consumer, conscious of, caring for and connected to the microbiome.

## Use and Clothing Care

New fabrics and materials have seen a trend in consumers washing less. Many garments and products now require new forms of biocleaning, which has created an opening in the market for consumer products and biocleaning services. Many high-end apparel brands offer mending and cleaning services for biogarments in store, or as a person courier service. Other independent cleaning businesses have set up biocleaning and biorepair shops to meet demand.

With many of these new fabrics and products being recent launches, brands want more information about the wear and tear of their garments. Therefore customer care has become a very different space of continual dialogue and feedback through social media platforms. What was once the role of bloggers to promote new products has been handed over to the consumer in an attempt for these brands to be completely transparent in the bioage.

Storing these new fabrics saw the design and patenting of the Biowardrobe™, a climate controlled wardrobe specifically designed for biomaterials. Early designs of products had issues with garments deteriorating; discolouring, mould and moth problems and even causing damage to material of different species, in one case a pair of bacterial denim jeans ate a biosilk shirt. These events instigate further development of the materials but also opened a new specialist market within furniture.

## End of Life

Within the bioindustry clothing waste to landfill has been greatly reduced with most garments being biodegradable. Thanks to the circular models embedded within this industry from the beginning and the shift to more biomimetic design, bioproducts are focused on low impact or giving back to the planet.
Alongside this we are even seing garments that pay forward, with embedded materials that give nutrients to the soil, feed plants and even grow wild flowers.

Those garments and products that can biodegrade in the soil or a domestic composter are given back to companies for recycling, industrial composting and data collection. With many of these new fabrics and products being recent launches, brands want more information about the wear and tear, biological stability and structural changes of their garments. This is a welcomed phase of R&D not only occurring during product development but the start of an on-going dialogue between brands and consumers to improve products, ensure low environmental impact and sustainable practices.

At the other end of the scale there have been some issues with DIY and biohacked garments causing problems in local micro biomes. With the open access to CRISPR technology and ongoing issues with legislation and biolaw, some biogarments are being produced for sale in illegal markets. Safety measures and protocol are often not followed in order to cut costs, this has created a loophole where synthetic microbes that are not classified for use in the production of products for retail.


Fig 33: Bioarchive Logo, Hannah Hansell (2017)

## Bioarchive

BIOmatters is framed within a future Bioarchive, which exists both physically and digitally. The model of an archive was chosen as a vehicle that can layer, interconnect, categorise and historicise narrative. As the project has highlighted a number of prevalent yet complex themes, an archive was also chosen as a platform to bring together a web of complex debate through speculative artefacts. And to compliment multi-disciplinary outcomes of creative practice ranging from photography to biogarments, to biosamples.

An archive requires a system, cataloguing, preservation and an archivist. Through this process I have become the archivist, it has helped me to question the work in different ways, Derrida argued, “The archivisation produces as much as it records the event” (Derrida, 1996, p.16). I have found that working in a manner where I am ‘archiving the future’ has pushed me to ensure clarity in the artifacts as individual pieces and as a whole collection. And to question how much archives will or will not change, when this process of archiving holds such importance to the artifact, event and people who engage with it. The archive is formed of 3 key components:

## Digital Archive

The digital archive takes the form of a simple website inspired by the VADS, an online resource for visual arts used by universities such as Goldsmiths, UAL, UCA and research centre's such as The Goldsmiths Textile Collection from The Constance Howard Centre and The Crafts Study Centre, UCA Farnham. The digital archive holds photographic works that are only available online as well as photographic records of the physical artifacts. It also contains all of the artifact information in the form of core records, which have been designed to build narrative around the objects. The archive can be found online here: https://hwestwood1.wixsite.com/bioarchive

## Physical Archive

The physical archive is a series of archival boxes of the objects that have been cleaned and conserved. Some pieces are stored together, for example the biosamples; others have their own boxes. These pieces have been designed as an exhibition piece where visitors would engage with the objects as if in an archive. The archive comes with handling gloves and labelling that correlates to the digital records where more detailed artefact information can be found.

## Labelling System

The labelling system for the archive has also been developed from the VADS online resource, looking at different types of artefacts from shoes, to textile samples, garments and photographs. Key categories have been picked to develop different parts of the narrative from date to production method, copyrights, materials to techniques used, size to information about the object, keywords to source and accession. This allows the scenarios and narrative to discuss issues such as IP and ownership of bespoke biomaterials, technological developments, biofacturing methods, new tools and techniques, how different parts of industry may emerge or new aftercare and disposal systems.

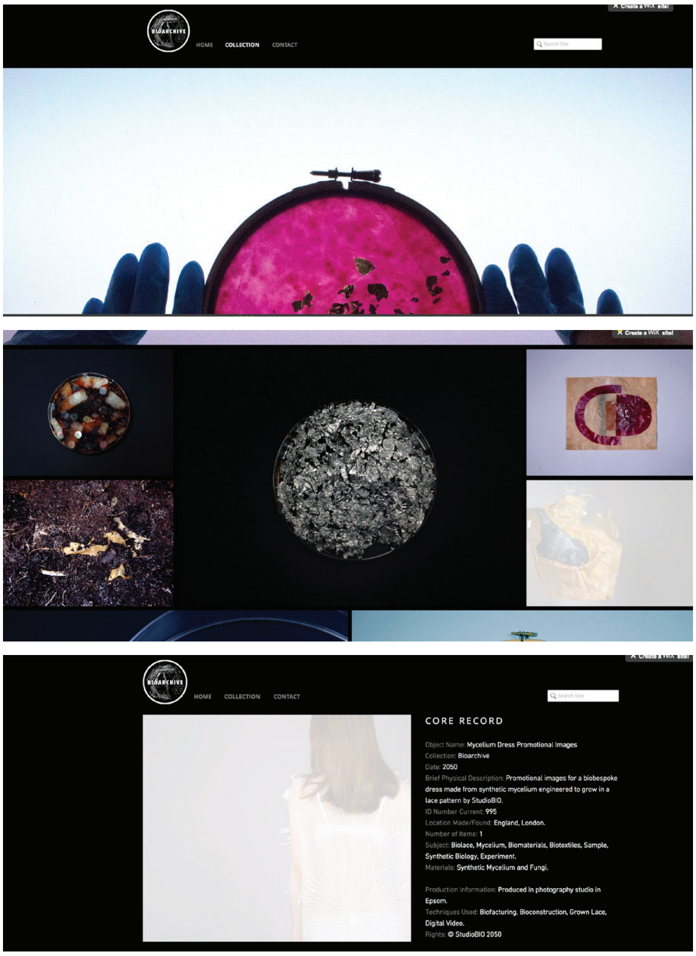



Fig 34: Bioarchive Website, Hannah Hansell (2017)


Fig 35: Bioarchive Archive Boxes, Hannah Hansell (2017)

# Bio-artefacts

The following pages aim explain the bioartefacts created for the bioarchive. Within this workbook some of the speculative bioartefacts and underlying narratives have been categorised together in terms of their concepts and themes. The format of explaining the bioartefacts/ narratives aims to connect the theories and emerging themes highlighted in the review to the design propositions created in the form of the bioarchive and bioartefacts.


Fig 36.1: Biotunic, Hannah Hansell (2017)


Fig 36.2: Excavation of Biotunic, Hannah Hansell (2017)

# Biotunic

# ID Number: 078/9

This piece addresses a potential DIYbio trend and movement where designers and hobbyists are working with microbes to produce biogarments. The pieces aim to discuss the trend of current biohacking spaces where anyone can join and engage in basic biohacking. This piece looks at how in the future this could become a standard design tool for creatives and non-professionals working on DIY craft projects. It does this through the basic design and construction of the garment, showing that it has been made using domestic processes for example through the basic stitching and finishing and the experimental quality of the design, dying and overall aesthetic.

There are 2 components to this piece, 1 is the actual garment boxed and preserved in the archive. The other, images of the garment being excavated from the site it was found at documented on the website. The addition of the photographs is to support the narrative of future biogarments being biodegradable. It also aims to create discussion around whether such materials will actually achieve their stated disposal. We can see biodegradable materials in industry at the moment, but they require industrial composting environments in order to fully biodegrade. Will we see similar issues with future biomaterials that they do not meet their expectations?

## Emerging Themes

Design of Biology

DIYbio

Biodegradable Materials

Danger of producing more of the same Non-degrading harmful materials

New Paradigm of Design

Biohacking

Novel Design Opportunities

## Scenario Topics

Design and Production

Materials

Use and Clothing Care

End of Life

Fig 37.1: StudioBio Logo, Hannah Hansell (2017)

Fig 37.2: StudioBio, The Living Collection Underwear Promotion, Hannah Hansell (2017)

## StudioBio — Narrative

StudioBio is a hypothetical bioapparel company brand founded in 2025. The idea behind this brand is that the current landscape of biomaterial industry is shifting; we are seing new start-ups, designers working at these start-ups and collaborations between scientists and designers more readily occurring. Also competitions such as the Biodesign Challenge and courses such as MA Material Futures CSM are producing designers and teams who are setting up their own start-up companies. The recent announcement of the partnership between CSM and LVMH and The Burberry Foundation awarding 3million to the RCA to establish the Burberry Material Futures Research Group, shows a shift in industry investing in research and new collaborations. If we put this into the context of a future where the materials and production methods of the textile and apparel industry have opened their doors to a new portfolio of biomaterials, there will potentially be new types of business and brands emerging in this space.

Alongside this it connects to the potential retraining of designers being versed in biodesign and the tools and techniques of this new field of design. StudioBIO is a company set up by 2 designers, one who has completed a PhD at the RCA in the school of material engaging with the Material Futures Research Group and the other at CSM in MA fashion engaging in the Sustainability and Innovation Programme funded by LVMH. Through a collaborative project and independent collaborations with synthetic biologists, fashion promotion and marketing and fashion business students, they decided to set up a new venture bringing their research and expertise together.

### Emerging Themes

- Emerging intra-disciplinary and cross-sector companies
- Design of Biology
- Biomarket and Industry
- Biobespoke
- Biology - Toolbox for Designers
- Potential to create bio-based alternatives for F&T industry
- Novel Design Opportunities

### Scenario Topics

- Design and Production
- Materials
- Consumer Behaviour
- Retail

Fig 37.1: Biofoiling Sample, Hannah Hansell (2017)

Fig 37.2: Bioapplique Sample, Hannah Hansell (2017)

# Biosamples

# ID Number: Various

A selection of early stage tests and samples from StudioBIO, where they were starting to 'biofacture' and 'grow-make' (Collet) new types of biotextiles from a range of engineered and synthetic microbes. The samples range in their process and technique, exploring how textile design techniques might translate into biotextiles. Some of these samples were developed during the designer's time at the RCA through the Material Futures Research Centre. Samples include biological versions of applique, printed textiles, embroidery and embellishment, lace, foiling, construction methods and different fabric types such as chiffon, leather and denim.

The idea behind these samples is that textile archives always have samples or samplers of cultural and historical techniques within their collection. The samples take from this idea as a documentation of early developments in 'biofacturing' and biotextile design. The pieces are a development on from Carole Collet's Biolace works and aim to try to continue this method of using critical design to present viable speculations.

## Emerging Themes

New Organisms

New Classifications

Growth & Cultivation

Biofacture

Novel Design Opportunities

New Vocabulary

New Materials

## Scenario Topics

Design and Production

Materials

Fashion and Textile Industry and Business

Response to Climate Change


Fig 38.1 & 38.2: The Living Collection Underwear, StudioBio, Hannah Hansell (2017)

## The Living Collection Underwear ID Number: 895/6

A set of underwear, bra and knickers designed to offer anti-bacterial properties through impregnated mycelium that eats sweat and body odour. Designed and manufactured by StudioBIO. During their time at the RCA and CSM the 2 designers collaborated on a project to develop a material for use in production of a relevant piece of apparel, a staple cotton garment that has a short life.

There are 2 components to this piece, 1 is the actual product packaged, branded and labelled. The other is a campaign for the product. The packaged product aims to communicate a few things, 1 is the brand and the lifestyle that they are trying to sell through the function of the garment. This lifestyle is a consumer who is concerned about personal health and hygiene but also about the planet. They are a consumer who want's to reduce their environmental footprint and impact and are therefore consciously paying more for biodegradable underwear. The other is through the packaging and how consumers will interact with this product at purchase and use. The piece is vacuum packed with a bioplastic in order to keep the microbes in stasis within the product. Finally the labelling and the narrative that this opens up around a need for new care symbols and guidelines for consumers purchasing biogarments.

### Emerging Themes

- New Materials
- Biodegradable Materials
- Biofactured materials now entering industry
- Design of Biology
- Biology - Toolbox for Designers
- Semi-living Garments
- Potential for Small-scale Distributed Production

### Scenario Topics

- Design and Production
- Materials
- Fashion and Textile Industry and Business
- Retail


Fig 39.2: Care Labels, StudioBio, Hannah Hansell (2017)

## Care Labels

## ID Number Current: 137

With the addition of new material classifications in the textile and apparel industry, new care guidelines for these garments and materials will need to be developed. This proposition aims to show what care labels might be made of, contain and how new care symbols would need to be developed for standardisation requirements. The pieces also hint to other care issues such as the potential need for new types of storage for biotextiles, it does this through suggesting a 'biowardrobe' and 'biocleaning' which suggest new business opportunities and systems. It also aims to discuss the need for a shift towards circular systems of production through the biodegradable symbol and instructions for some items to be dug into the ground or composted after use.

### Emerging Themes

- Biocare
- Biodegradable Materials
- Values, principles and standards entering the liliving world
- Biofactured materials now entering industry
- Novel Design Opportunities
- Circular System's needed

### Scenario Topics

- Use and Clothing Care
- Fashion and Textile Industry and Business
- Retail
- End of Life

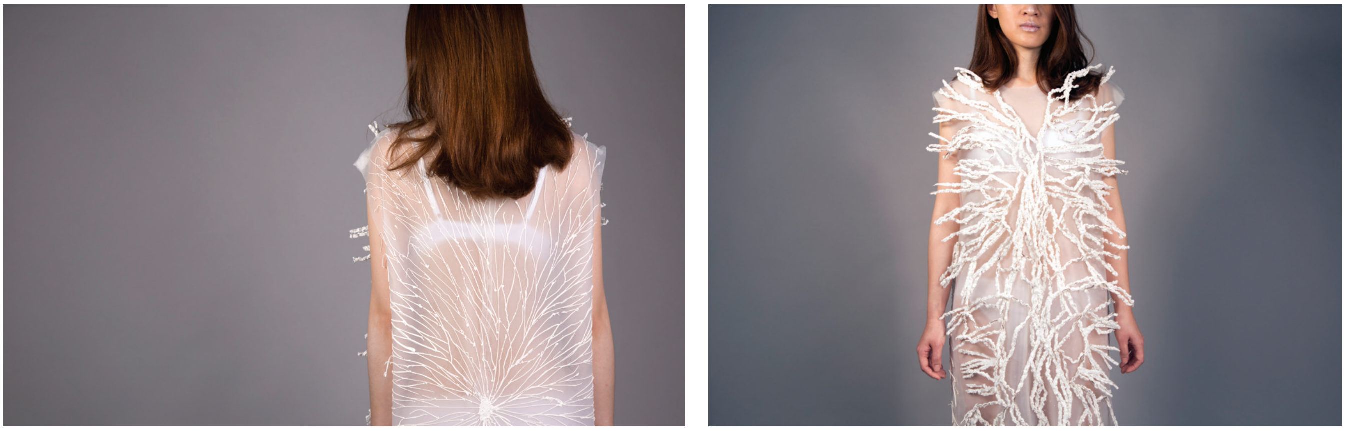


Fig 40.1 & Fig 40.2: Mycellium Dress Promotion, Hannah Hansell (2017)

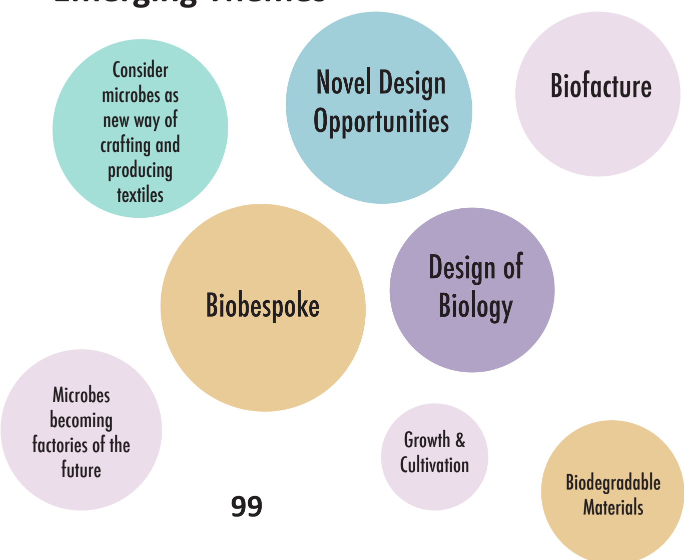
## Mycelium Dress

## ID Number Current: 995

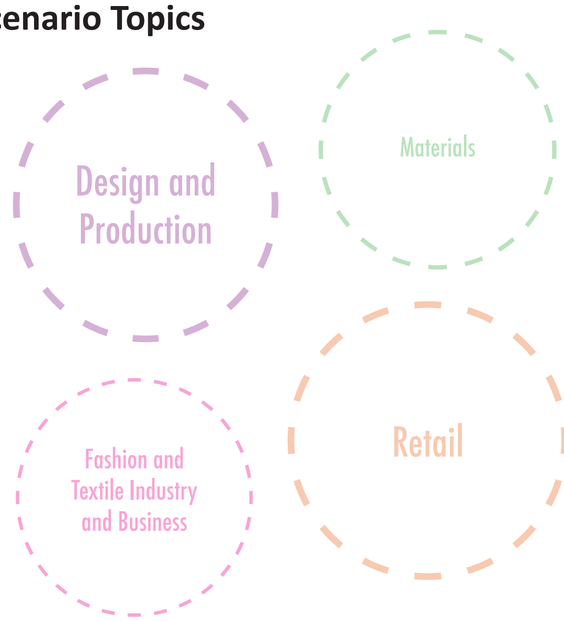
This dress is a couture piece, biobespoke, made, as an example of how the company Studiobio can cater to clients needs for customisation and personalisation at a biological level. Made from synthetic mycelium engineered to grow in a lace pattern, the dress is the first of it's kind. There are 3 components to this piece, images of the cress as aretfact, promotional images of the dress and a promotional video.

The piece is a development on from Carole Collet's Biolace works and aim to try to continue this method of using critical design to present viable speculations. There is the addition in this piece through the use of mycelium that these samples would be used to breakdown carbon and pollutants in the air. Mycelium would also utilise some of existing functions as an organism made of countless hyphae that communicates to its counterparts by using a web like network. The mycelium has been reprogrammed to utilise this communication system to construct lace patterns. On disposal of the garment when dug into the soil it would work further to remove and reduce the harmful effects of certain toxic contaminants.

### Emerging Themes




### Scenario Topics



# Analysis and Critical Discussion on Outcomes

The aims of this project were: to explore whether critical/speculative design approaches can be utilised to research and question the potential of biosynthetic technologies in the textile and apparel industry. To review the existing and emerging landscape of biodesign, biotechnologies, synthetic biology, biodesigners, bioartists, bio start-ups and emerging design paradigms based on cultivation, growth and living cells. To explore whether biosynthetic technologies could offer sustainable solutions, new materials and circular models, to tackle key industry issues. To create work that can be exhibited or utilised in education settings to instigate debate about the role of design in Synthetic Biology by future designers and design educators. And finally to create a series of design objects/speculative provocations that, pose and address the research question. The creative practice outcomes will be discussed in relation to the literature review, emerging themes and the project aims discussing the archive as a whole and specific artefact's. There will also be a critique of the methods used, with particular focus on creative practice as the main method used at this stage. Further analysis will be conducted once data from focus groups and interviews is obtained at a later date.

## Bioarchive

Overall the archive acts as an anchor to bring the bioartefacts and therefore the interconnecting narratives together in one space. On reflection this is a much larger piece of work as the archive could contain a range of different objects from varying periods in order to bring current technologies and products into focus against future speculations. For example what if the archive contained a spider silk bolt threads tie, or adidas futurecraft trainer alongside my own objects? And works by Victoria Geaney, Amy Congdon, Carole Collet highlighted in the review. I feel the archive is only just scratching the surface of its possibilities. It also does not encompass the full range of microbes currently being investigated and engineered.

What the archive does do is start to create a piece of critical design that questions the potential of biosynthetic technologies in the textile and apparel industry. It has created a piece of critical design that can now be used to collect data on participant's feelings about this potential future and what the work communicates. The archive aimed to bring out key themes from the literature such as how things might be made in a biological future, linking to Collet's notion of 'biofacturing' and theories of 'grow-made' products. It also aims to align with Oron Catt's and Iona Zurr discussion around critical reflection and cultural analysis needing to be used to understand synthetic biology's most effective path. An archive and artefacts performs this function, therefore this overall model seems a relevant choice. Catt's and Zuur also discuss that design blending into art practice can be used to investigate philosophical and aesthetic issues raised by new materials. I feel the work raises aesthetic issues as peer and tutor reaction in critiques has been varied, some people are interested in the grown material, others find it unattractive. Philosophically I need more feedback from a wider audience; hopefully I will gain this data during the exhibition.

## The Living Collection

The living collection underwear by StudioBio aimed to discuss issues with a lack of circularity in design and a mind-set of disposal by consumers. An issue raised by Carole Collet, Daisy Ginsberg and Kate Fletcher in the review. The pieced aimed to suggest whether we could address these issues through a new paradigm of design, one informed by and entwined with biology. It also aimed to discuss issues with speed in the fashion and textile industry and the lack of correlation between material type and longevity of use. Mycelium was chosen as a material that has healing properties, but one that could also clean and then biodegrade itself, paying forward with nutrients when dug into the ground. The piece also aimed to discuss questions around cleaning, aftercare and disposal of such materials, issues and opportunities raised by Suzanne Lee and Carole Collet. These ideas connect to my own 'circular biodesign' models developed last year. I feel there is space to develop this work further as much of the work created for this project is dealing with the lifecycle of these hypothetical products - production, manufacture, retail, aftercare and disposal, therefore it is a rich area for potential artworks.

## Biotunic

Connected to this is the Biotunic, which aimed to raised questions around whether new biosynthetic materials will be more sustainable and in particular biodegrade at the pace imagined. The piece discusses issues raised by Daisy Ginsberg around whether synthetic biology will simply be a way of churning out more stuff. That it will promise more than it gives and actually leave us in the same position we are currently in simply with a new classification of materials that don't degrade and cause more harm than good. The piece also aimed to discuss the emerging industry and engagement with this new technology by setting a narrative of a DIY bio crafter who created the garment in her garden studio. It aimed to question where this technology would develop most effectively, seing DIYBio and Biohacking as a collaborative space for exploration, learning and sharing. But also having potential dangers for the creation of unregulated species and materials that could harm the microbiome.

## Biosamples

The range of biosamples created by the hypothetical company StudioBio aimed to create a series of experimental biotextiles consistent with Carole Collet's discussion around new classifications and properties of textile in her post 2050 research scenario. And Daisy Ginsberg's discussion around the potential of synthetic biology to condense production methods. It aimed to fabricate some of these ideas in combination with current scientific research and development. Some of the samples are already feasible such as the biopaper, examples created by igem teams such as aqualose, others proposed by biohackspace, the juicy print project, inspired the creation of bioapplique. The intention of the samples is to distil the research engaged within the review with my own explorations of growing bacterial cellulose throughout the year. Some of the samples were created more intuitively, others had specific intention. More work could be done to refine these samples, however they were presented as early stage tests by the hypothetical company for this very reason. The aesthetic of the samples is therefore intentionally experimental in order to convey these ideas.

## Mycelium Dress

One of the key aims of the Mycelium Dress piece was to address points raised by Daisy Ginsberg, Oron Catt's and Iona Zurr in the review that currently synthetic biology's rhetoric is to address humanities needs rather than our individual complex needs. On reflection I feel this piece has the potential to create a personalised garment that would develop greater connection between wearer and object. This potential comes through the photographs and the presentation and aesthetic of the material on the body in this piece. Seing the skin through the fabric and some of the model's poses create a sense of connection to the living matter. The work also connects to Carole Collet's discussion around the ownership of synthetic microbes by fashion houses and the potential for the ultimate biological customisation. The piece definitely requires the online archive record information to clearly communicate this position. It also follows on from Mauritzio Montali's work through the growing lab and the potential of mycelium to have double functions being material and remediation.

The piece took from this thinking and combined current developments in chemical based SMART textiles to present a potential personal cleaning material for the body.

## Labelling

The use of labelling creating core record information for the artefacts on the website has been essential in setting out the narrative of the pieces. It is in this space that I have tried to suggest issues around ownership through the copyright information. I don't feel that this has been so successful however as it is quite hidden in the work. What has been successful is the use of categories to highlight new design vocabulary in this biological era as suggested by Carole Collet and Daisy Ginsberg's research.

## Critique of Creative Practice Method

Creative practice has been the main research method used in this project, focus groups and interviews will be used at a later date as intended. Using creative practice as my main method has had benefits and challenges. The benefits being the exploratory and iterative nature of this method, allowing reflection, analysis and intuition to guide the process. The challenges have been working along, keeping momentum and action planning from analysis and reflection. But creative practices offers something unique in this area of research, a space to challenge, critique and communicate a complex and uncertain future.

The range of objects created as speculative artefacts have offered me a way of distilling, whilst interconnecting a number of ideas. From the overarching themes of biodesign, biofacturing and biomaterials to the more nuanced narratives of how and why studiobio was set up, early DIYbio and the potential of biobespoke services. This has been constructed in different ways through the branding of the archive, the labelling of each artefact and presentation of these components down to the font choice, camera angle and hand stitching, everything has been designed and considered.

I have realised through this project that I am process led and that this can be a difficult way of working when you are trying to create speculative outcomes that need a specific narrative in order to communicate the idea effectively. However looked at from a different angle, I feel that this has been the strength of many of the artefacts as I have made them intuitively based on the contextual and visual research. I have allowed my textile skills and the connection between the materials and how I have worked with them as a biodesigner, a bioartisan and worked as both a process and research led practitioner.

Working with photography has been important in the speculation and narration of the works. Taking the objects into the photo studio, setting them up, making them into props and creating a visual aesthetic through the editing and manipulation of the images in Photoshop has all played a key role in the overall narrative setting.

I was unsure about the archive idea, but on reflection it has allowed me to expand and play with the narrative on different levels adding layers of information, themes and debate. I feel that I need more time to make it a concrete representation of the breadth of my subject. I often felt that I was trying to do too much and not able to give enough time to each artefact, whilst at the same time wanting to create a range of pieces so that the overall archive was realistic. I think until I present and then exhibit the work it is hard to fully reflect. I need to see the work in different contexts and be able to set the work out for people to engage with and then gain feedback. And most importantly to see what the work does, whether it instigates debate or not, in order to full analyse the method.

# 05: Conclusion

## Conclusions

We are faced with a range of complex issues from depleted resources, to a changing climate, a growing population and key environmental issues. The fashion and textile industry has key problems that need to be addressed now. We cannot keep taking, polluting and wasting as much material as we currently are. Instead we need to work towards returning this industry to a 'World-Making' one once more. Circular systems need to be adopted and ways to stop or reduce the industries pollution through less harmful substances and/or new processes. In this landscape I believe that we need to truly consider whether the manipulation of microbes could become a new way of crafting and producing textiles in the future and not just a speculation. Whether the way to remedy these issues can be through a materials revolution, new systems of production and new technology.

It is clear that synthetic biology has the potential to offer solutions to current energy, healthcare and material issues, but it also brings a range of unknowns and with that fear. On the positive side it offers the opportunity to produce existing materials more efficiently and completely new materials. It could champion small-scale distributed production, moving us away from the petrochemical centralised, mass production model. On the negative side there is a danger that engineering biology will just produce more matter with the same production, consumption and linear systems that it does today. It is unclear yet as to whether it can be more sustainable solution. We might simply be switching our energy source and but keeping monoculture farming, with even more challenging large-scale effects. As this technology is still in its infancy once industrialized it might simply end up giving a 'green gloss' to harmful practices.

Issues around control, IP and patenting of living organisms within this biotechnology raise morally and ethically complex questions. There are also dangers around such a technology and synthetic organism's falling into the wrong hands and being used for bioterrorism, being hacked in order to carry out harmful acts, dangers of exploitation and monopoly of the human genome as a space to be engineered. In this space existing life becomes abstracted, but artists and designers can play a cultural role in highlighting such potential monopolisation. They can also play a key role in advising on the development of this technology by bringing knowledge from each stage of the lifecycle of a product on a hypothetical and practical level if collaboration becomes more common and funded.

It is evident that there is already an emerging group of designers, artists, start-ups and theorists working in this area. Within them a number believe that a new paradigm of production is emerging based on cultivation and growth, driven by this materials revolution. Biofactured materials are now beginning to enter into retail through examples like the adidas futurecraft trainers and Bolt Threads Biosilk tie. Companies at varying levels are working towards a common goal of creating more sustainable materials, systems and products for the fashion and textile industry. On an amateur level DIYBio and Biohacking is emerging and offering a collaborative space for exploration, learning and sharing. The DIY, community, hacking and material activism space could be the area to look for methods, values and systems for this new paradigm. This is an area for further research as these communities expand.

As it becomes more and more likely that biology will become a toolbox for designers, this marriage of design and biology will require a review of varying ways we have and continue to learn from and manipulate life and the way in which we make and consume goods. We need to look at how we learn from nature in order to tread a different path in the way we design, make and produce things. Issues with a lack of circularity in design and a mind-set of disposal by consumers could be addressed through a new paradigm of design. This new paradigm of production could offer new systems that are diverse, circular and complex. What we need to be aware of it that there is potential for real development and change to be over looked, of the novel design opportunities and the unique issues that such a living technology presents. In this new paradigm of production, it seems evident that a new paradigm of design needs to emerge.

If we move to ‘biofacturing’ materials and garments made by living cells, production, design, aesthetic and function of fashion could completely change. Along the way we need to consider whether consumers will want to wear semi-living garments, or garments made by genetically engineered species? Synthetic biology could reshape the classification of materials and textile vocabulary, as we know it. Varying levels of industry could take on these new materials and methods of production in different ways. Bioapparel could shape a different retail experiences and the disposal of biotextiles/bioapparel could be as simple as putting used clothing into a compost bin in the garden.

From the outcomes created it is clear that critical design can play a key role in developing different narratives for discussion and analysis of this potential future. In order to do this effectively critical design needs to be research driven, critical and less speculative and hypothetical. It also needs to engage in critical analysis and reflection through applying relevant research methods, analysis and dissemination. Creative practice can be a closed off process, iteration, collaboration, primary data collection through the exhibition and presentation of work in cultural, academic and educational settings and on-going feedback is essential to the research process and development of this area of design.

# Limitations of Study

Four key limitations of this study have been identified:

Firstly, the research gained has been predominantly through secondary sources, books, journals, articles, reports and thesis. The study is therefore limited in its primary sources, though it does include attendance to relevant conferences. However interviews with speculative/critical designers and synthetic biologists and primary data collection of interaction and feedback on the practical work have not been possible.

Secondly, the objects and narratives have only been presented to a small group of viewers who already have a clear understanding of the work. Therefore any feedback and analysis of the work has come from a select group of designers and myself. This means that perspectives, insights and understanding of the work have not been gained from the wider community that the work is aimed at.

Thirdly, the practical outcomes have been created through an intuitive process of making and response to the materials, aesthetic and concept. Therefore at times the work might have missed opportunities of developing a multi-layered narrative through the use of ongoing critical analysis and reflection.

Finally the lack of connection to synthetic biologists and potential to collaborate on outcomes for the project potentially mean a missed opportunity to research and question the potential of biosynthetic technologies in the textile and apparel industry through primary investigation. The examples of successful projects in the review were highlighted as being those where collaboration took place utilising the technology, over hypothetical speculative design works.

# Opportunities for Future Research

Opportunities for future research for this project include engaging focus groups and interviewee's with the objects and gaining qualitative data from these pieces. My initial aim was to carry out the focus groups prior to completing this thesis. As with many project plans this didn't work out, I ended up making the practical work right up to the summation. However I set the aims in this project so that I could complete the work and then utilize it for feedback and data collection. Therefore exhibiting the work in various settings for further feedback and data collection is a key opportunity.

I also feel that there is opportunity for further development of works from the scenario developed within this thesis addressing interconnecting topics and themes. The emerging themes drawn out of the review and scenario covers a wide area within my research topic. I feel that the outcomes created have only just started to scratch the surface of potential dialogue and narratives. For example I have not really touch on bioethics within the work, which is an important discussion to address within this topic. Either this or to expand the archive to include the work of artists, designers and start-ups included in the review to develop a wider historical range and bring together the framework for designing with the living suggested by Carole Collet through the archive.

In terms of design practice I also feel that the research only scratched the surface of exploring whether a new form of design practice will need to emerge and what this might look like. I feel that this is an important area of research that would require doctorate level investigation to effectively explore.

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