Factories of the Future – Synthetic Biology: A Sustainable Technology for Future Textile Manufacturing?

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Introduction

It is predicted that by 2050, we will reach a global population of 9.6 billion people, a growing population that will need to clothe and feed themselves (United Nations, 2013). Today, key resources such as oil, a main raw material of the textile and apparel industry, is running out; fresh water resources are stretched and agriculture is beginning to suffer the effects of climate change (Ackerman and Stanton, 2013). It is estimated that the current global population is using 50% more planetary resources than is available (Moore and Rees, 2013).

Fashion is currently the second largest polluting industry on the planet, after oil (Deloitte, Danish Fashion Institute, 2013) with the textile industry discharging billions of tonnes of waste and toxic chemicals from its production processes every year. In 2015, the total amount of clothing and textile waste in the UK per year was approximately 2.35 million tonnes. The speed and scale of this linear use of resources is unparalleled and causing the textile industry to be stuck in an outdated model that promotes consumption and linear systems over longevity and circularity. 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 turning to new technologies and materials be the answer to drive change?

> *"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)*

Biologists working in the field of synthetic biology and genetic engineering are developing methods for 'reprogramming' organisms such as bacteria, yeast, algae, plants and mammalian cells to produce bespoke materials, medicines and biofuels. This paper explores whether manipulating living organisms could become a new way of crafting and producing textiles and apparel in the future and if so what implications this could have for the industry if a 'Biorevolution' comes to pass. It does this by discussing an on-going research project 'BIOmatters'.

BIOmatters

'BIOmatters' is a practice-based research project conducted from September 2015 to August 2016 at the University of Brighton. Using a combination of critical design (Dunne & Raby, 2013) and contestable design (Catts & Zurr, 2015) it speculates whether synthetic biology could become a sustainable technology for future textile manufacturing. Offering alternative future scenarios that are hypothetical but informed by the actualities of new scientific knowledge and technological developments, the work aims to question and make sense of the impact such developments could have. To open up debate as to whether this is a path we want to take and reflect on the potential of critical and contestable design to question this developing technology. Informed by a literature review and scenario frameworks a series of speculative samples, photographic fictions, films and models are discussed in this paper to open up discussion about this emerging technology.

Synthetic Cells - Factories of the Future?

Some people predict that biotechnology will be a key driver for change in the 21st Century. The World Economic Forum recently reported Systems Metabolic Engineering 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 offers the opportunity for living things 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).

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). Opportunity for new resource streams and materials, design practice and education, markets and services could also emerge. 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). Complex issues that are not often discussed such as the path that the technology is taking and the path that we want it to take. What future scenarios could unfold in the textile and apparel industry?

'Biofibres' and 'Biofabrics'

If we start to genetically engineer cells to produce raw materials, completely new fibres could be born along with a new stream of production for existing fibres. 'Textile Fibres 2050+' (Figure 1) is a diagram produced through 'BIOmatters' proposing a new section to the textile classification table of synthetic cells such as bacteria, algae, plants and yeast. Examples of such fibre development are happening in industry today, from Modern Meadow's tissue culture leather, to Spider and Bolt Threads spider silk from reprogrammed bacteria, to Biocouture's bacterial cellulose leather.

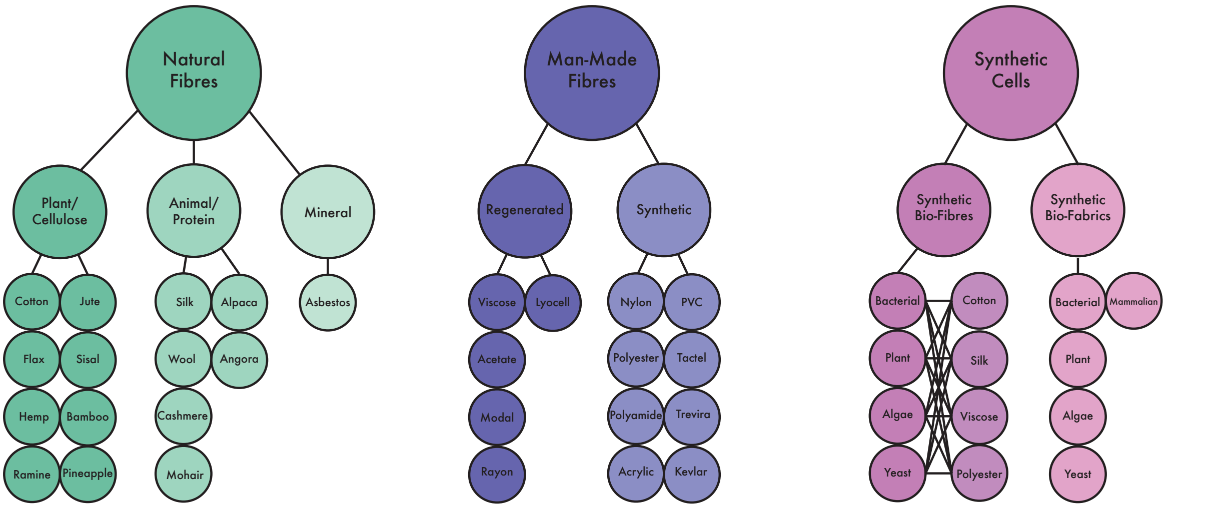

Figure 1: Textile Fibres 2050+

If we take this a step further into the future, 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).

Circular Biodesign

'Circular Biodesign' (Figure 2) is a model in the process of development as part of the 'BIOmatters' project that proposes a future circular, self-contained, biological system for these 'biofibres' and 'biofabrics'. Informed by circular economy principles and models (Ellen MacArthur Foundation, Goldsworthy et al) it applies systems thinking to propose a model for the textile and apparel industry.

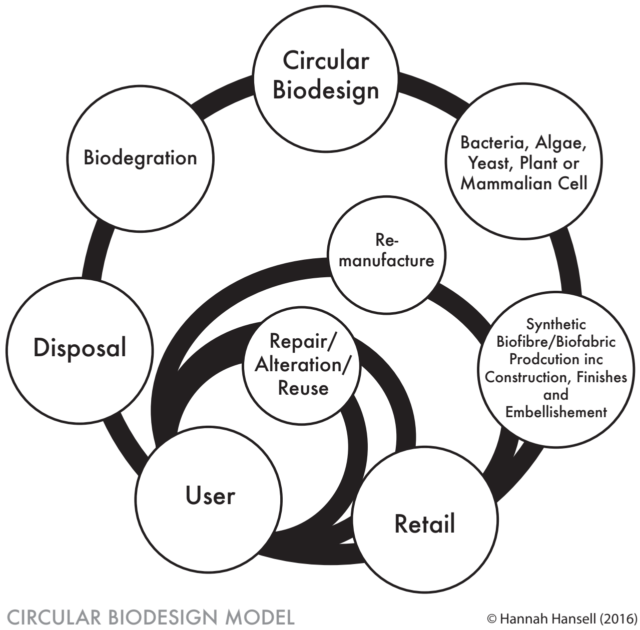

Figure 2: Circular Biodesign Model

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 offers 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. This means that programming finishes, lifespan, embellishment, fabric construction and properties into the DNA of the living factory would be possible 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.

'BIOmatters' also explored this future production system through a series of speculative samples under development by a hypothetical Biotextile lab. 'Client Samples and 'Biovoré' (Figure 3) are photographic fictions of experiments with time-consuming, toxic and harmful existing processes of embellishment and decoration to biofabric. 'Biovoré' for example is an experiment to try and create devoré velvet without using the usual chemical processes of sodium hydrogen sulphate. This process would take away the need for such chemical use, as the bacteria would be programmed to grow the velvet pile in certain pre-programmed areas to create the pattern effect desired.

Figure 3: ‘Client Samples and Biovoré’

Biomarket

Production systems relevant to the varying speeds and scales of the textile and apparel market could also be developed. Pushing the circular biodesign model further ‘BIOmatters’ developed a variation of production models across a breadth of future markets (Figure 4-7). These market levels take from existing industry structures proposing revised markets in a future bio context.

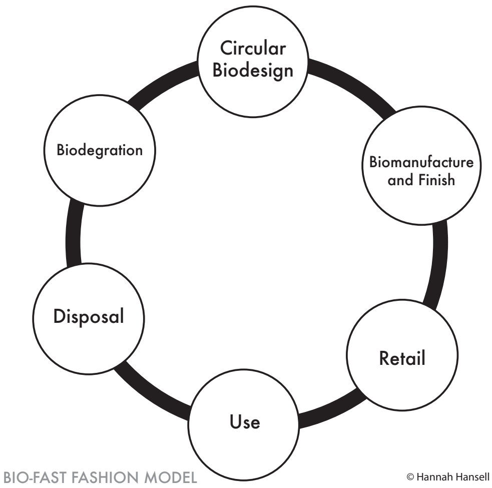

Figure 4: Bio-Fast Fashion Model

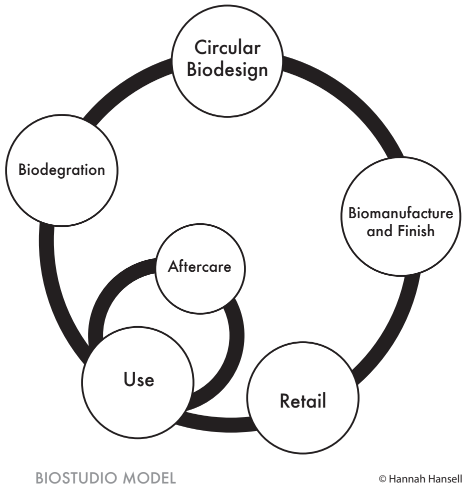

Figure 5: Biostudio Model

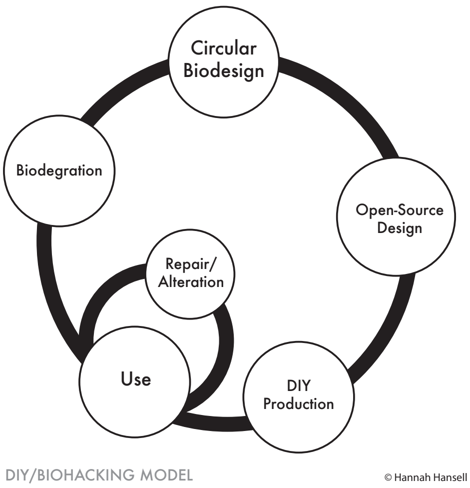

Figure 6: DIY/Biohacking Model

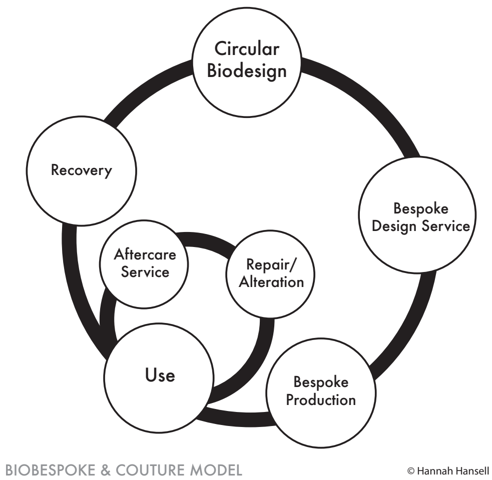

Figure 7: Biobespoke & Couture Model

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.

Consumer Perception and Services

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.

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).

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. 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.

Design Education

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. BIOmatters explored this future landscape through the creation of a series of photographic fictions of a hypothetical Biotextile lab where a textile designer of the future is at work. 'BIOstitch #1 and #2 (Figure 8&9) comprise of a future textile designer working in a hybrid environment. The images present a workspace that is somewhere between lab and design studio, where the subject engages with reviewing, testing and draping biomaterials. The lab is developing materials for the fashion and textile industry by reprogramming the bacteria to produce pre-embellished and pre-dyed biomaterials in engineered patterns.

Figure 8: BIOstitch #1

Figure 9: BIOstitch #2

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.

Challenges

The work presented so far in this paper is based on the premise of the circular economy being practiced in this future 'biotextile and apparel industry'. There is of course a high chance that this technology will be used within a linear system and that unsustainable practices will continue to be utilised, simply replaced with new materials. As an emerging technology that manipulates life there are also risks and complex ethical issues that need to be discussed.

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. 'StudioBIO' (Figure 10) is a speculative video produced as part of 'BIOmatters' that present a hypothetical biotextile company offering bespoke biofabric production for the textile and apparel industry. The video narrative has questionable dialogue about the services on offer in relation to ethical and environmental claims. The aim of this piece is to make viewers consider and question the possibilities and challenges that such a future market could bring around exclusivity, cost, ethics and patenting living cells.

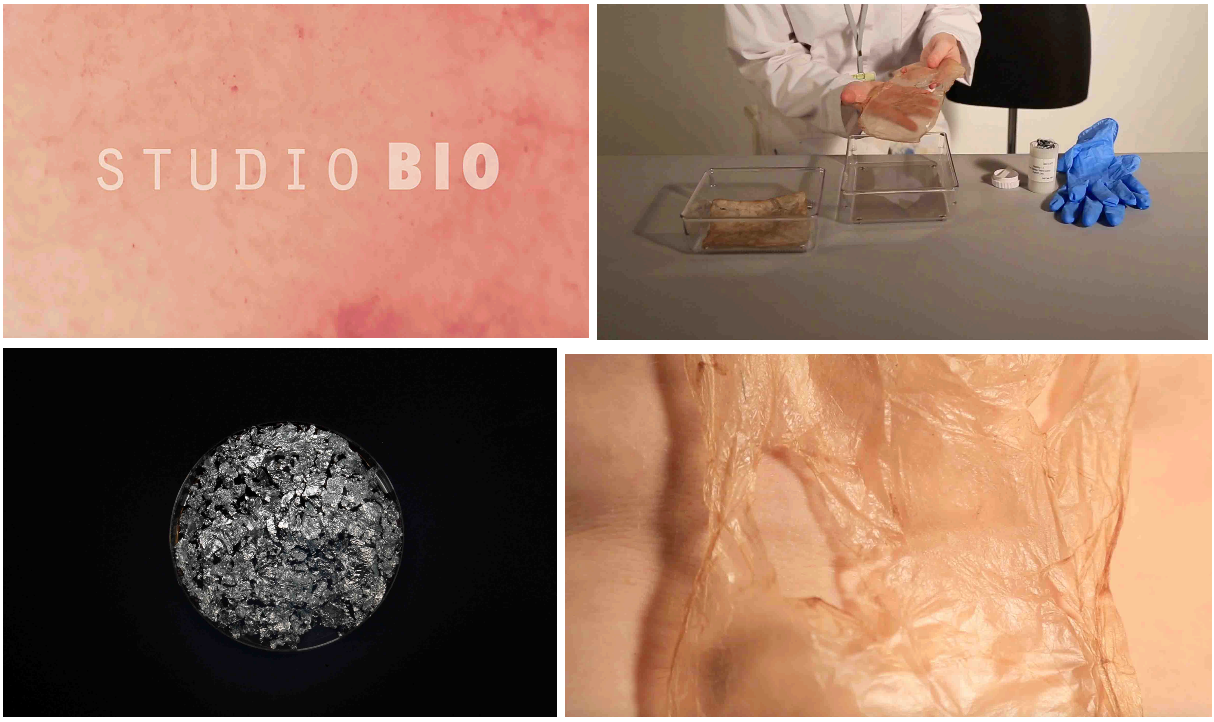

Figure 10: Film Stills from 'StudioBIO'

Feedstock

Living factories are very different systems to oil based production. 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 bacteria 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 as well as ourselves and our livestock? Can such large-scale monoculture farming be sustainable? (Ginsberg, 2015)

1st Generation Industrial Biotechnology

There is 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' (McDonough, 2002) to meet demand. 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 it 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 microbiome. Organisms released into the earth will require biosafety regulations and intellectual property control.

Conclusions and Future Work

This paper has proposed potential opportunities and challenges should manipulating living organisms become a new way of crafting and producing textiles and apparel. As critical and contestable design these outcomes function as works for debate and further conversation as the technology develops. In relation to current issues within the textile and apparel industry it could offer the potential to develop new materials, circular systems and condensed production, counterbalancing the depletion of key resources and decline of oil. Reduce energy, waste and toxic outputs during manufacture and develop washing systems and products that reduce environmental impact. For me the works highlight the importance of exploring different ways of manufacturing with the living in order to develop more ecologically positive manufacturing methods. Good design practice for working with this technology will need to be developed. We need to design symbiotically with synthetic biology. Biotextiles and apparel would need to be developed as ecosystems, products in symbiosis with each other and symbiotic with existing natural systems.

It seems essential that whilst exploring we remaining critical of this emerging technology in terms of the risks and complex ethical issues it raises. Clear ethical guidelines will need to be developed if we start to produce products through these system to ensure such self-replicating technology will not cause a risk to our environment or us. We must question whether synthetic biology is the right direction to take or if there other solutions are more feasible and sustainable. It seems clear that we are not yet at a point of celebrating this technology but at one of interrogation and exploration in order to understand the limitations and expectations of Synthetic Biology.

BIOmatters will investigate consumer perception and biological aesthetic exploring what bioretail and bioservices could look like over the next year. Connecting consumers to these new products has highlighted itself as a challenge but also an opportunity to explore deeper connection to living apparel. My intention is to push work fully into contestable design through the final year of my MA, developing working prototypes based on emerging scientific knowledge (Catts & Zurr, 2015). It is clear that biological design needs to come out of the lab and into context, critical and contestable design offers an opportunity to scrutinise and debate this developing technology.

References

Ackerman, F,. & Stanton, E. A. (2013) Climate Economics: The State of the Art. London: Routledge.

Baldwin G., Bayer, T., Dickinson, R., Ellis, T., Freemont, P. S., Kitney, B. I., Polizzi, K. and Stan, G.-B. (2012), Synthetic Biology, A Primer, London: Imperial College Press.

Ball, P. (2001), Silk and chips. Nature News, Nature Publishing Group [online]. Available at: www. nature.com/news/2001/010531/full/ news010531-11.html (Accessed 20th April 2016).

Collet, C. (ed.) (2013), Alive, New Design Frontiers – En Vie, Aux Frontières de Design. Exhibition Catalogue. EDF Foundation.

Collet, C. (2012) BioLace: An Exploration of the Potential of Synthetic Biology and Living Technology for Future Textiles. Studies in Material Thinking, Vol. 7, February, pp1-12. [Online] Available from: http://www.materialthinking.org/papers/71 [Accessed 12th April 2016].

Dezeen and Mini Frontiers. (2014) *Microbes are the "factories of the future".*

http://www.dezeen.com/2014/02/12/movie-biocouture-microbes-clothing-wearable-futures/ (accessed 29/1/16)

Dunne, A. Raby, F. (2013) Speculative everything: design, fiction, and social dreaming. Cambridge, Massachusetts: The MIT Press.

Ellen MacArthur Foundation. (2013) Towards the Circular Economy. Opportunities for the Consumer Goods Sector. (Vol.2)

Enriquez, J. (2001) As The Future Catches You: How Genomics and Other Forces are Changing your Life, Work, Health and Wealth. New York: Crown Business.

ETC Group (2007), Extreme Genetic Engineering – An Introduction to Synthetic Biology [online]. Available at: www.etcgroup.org/issues/ synthetic-biology (Accessed 27th April 2016).

Fletcher, K., & Tham, M. (2015) Routledge Handbook of Sustainability and Fashion. Oxon: Routledge.

Ginsberg, AD., Calvert, J., Schyfter Camacho, P., Elfick, A., & Endy, D. (2014) Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature. Cambridge, MA: MIT Press.

Lee, S. and Du Preez, W. (2005) Fashioning the Future: Tomorrow's Ward- robe. London: Thames and Hudson.

McDonough, W., & Braungart, M. (2002) Cradle to Cradle: Remaking the Way We Make Things. New York: North Point Press.

Moore, J., & Rees, E. W. (2013) State of the World 2013. Is Sustainability Still Possible? Washington, DC: The Worldwatch Institute, Island Press.

Myers, W., & Antonelli, P. (2014) Bio Design: Nature Science Creativity. New York: MOMA.

OECD and The Royal Society (2010), Symposium on Opportunities and Challenges in the Emerging Field of Synthetic Biology, Synthesis Report [on- line]. Available at: www.oecd-ilibrary.org/science-and- technology/sympo- sium-on-opportunities-and-challenges-in-the-emerging-field-of-synthetic-biology_9789264086265-en;jsessionid=1kwxknihjtlmr.delta (Accessed 24th April 2016).

Science Daily (2010) Native-like Spider silk produced in Metabolically engineered bacterial. [WWW] Available from: http://www.sciencedaily.com/ releases/2010/07/100727121940.htm [Accessed 12th April 2016].

Synthetic Biology Leadership Council (2016), Biodesign for the Bioeconomy – UK Synthetic Biology Strategic Plan 2016 [online]. Available at: https://connect.innovateuk.org/documents/2826135/31405930/BioDesign+for+the+Bioeconomy+2016+DIGITAL+updated+21_03_2016.pdf/d0409f15-bad3-4f55-be03-430bc7ab4e7e (Accessed 21st April 2016)

UK Synthetic Biology Roadmap Coordination Group (2012), A Synthetic Biology Roadmap for the UK. Technology Strategy Board [online]. Available at: www.rcuk.ac.uk/publications/reports/synthetic biologyroadmap (Accessed 20th April 2016).

United Nations, Department of Economic and Social Affairs, Population Division (2013), World Population Prospects: The 2012 Revision, Highlights and Advance Tables. Working Paper No. ESA/P/WP.228.

Venter, C. (2013) Life at the Speed of Light. New York: Little, Brown.