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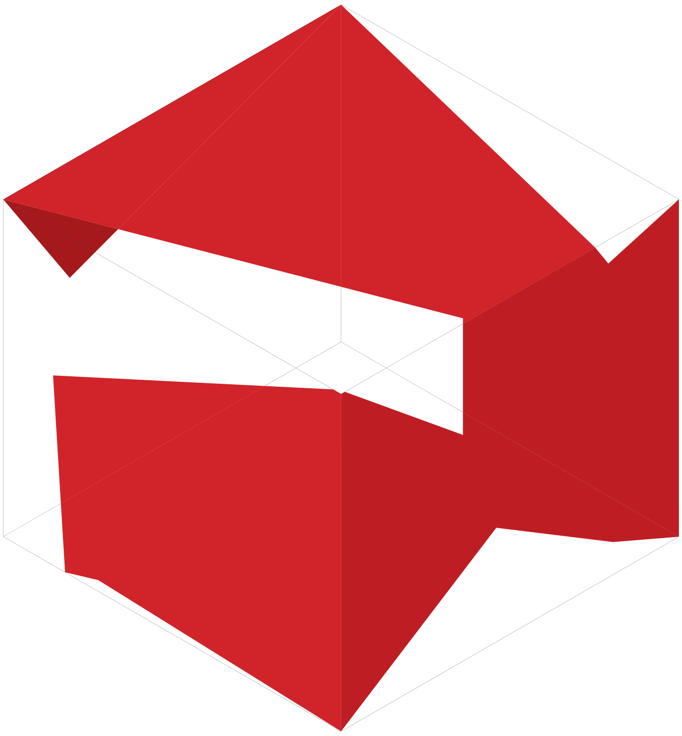

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BioLace: An Exploration of the Potential of Synthetic Biology and Living Technology for Future Textiles

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Abstract: Could emergent 'Living Technology'[i] such as synthetic biology lead to a more resilient future? This paper presents 'BioLace', a speculative design-led research project that investigates the intersection of synthetic biology and textile design to propose future fabrication processes for textile products and architecture. The motivation behind this research lies in the hypothesis that living technology can foster a new approach to address some of the key sustainable challenges of the 21st century. The BioLace project is designed to probe the potential of a biological manufacturing future by exploring the cellular programming of morphogenesis in plant systems. The project aims to translate synthetic biology into accessible design scenarios to expose and understand the societal implications of new emerging technologies. The BioLace project poses the following questions: Can synthetic biology become a potential sustainable technology for future textile manufacturing? Will crafting molecules become a new way to produce textiles? Could biology combined with nanotechnology enable us to engineer intelligence in materials to program smart and responsive biological textiles?

Keywords: Synthetic biology, living technology, future textiles, sustainable design, ethics

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BioLace: An Exploration of the Potential of Synthetic Biology and Living Technology for Future Textiles

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Societal Context

Inheritance of the Industrial Revolution

The past two decades have seen an increase in ecologically influenced socio-economic trends, amplified by a growing awareness of issues related to climate change, energy and water shortage. But when it comes to design and manufacture, most sustainable principles are circumscribed by the inheritance of the industrial revolution, which relied on the 'heat, beat and treat' processes described by Benyus. Although a clear shift has now taken place, most current sustainable design methodologies focus on 'top down' principles such as 'reduce', 'reuse', 'recycle', 'up-cycle', 'design for disassembly' or 'Life Cycle Analysis'. These principles help to enable cleaner and more efficient design and manufacturing processes and are necessary for the short- and medium-term future. They are, however, still embedded within the economic model of the industrial revolution. An economy empowered by technology and designed to foster mass consumption; a system that demands an ever-increasing exploitation of natural resources. These resources are now limited, endangered, and often polluted and unsafe. It is crucial to shift our models of production and consumption and to explore fresh perspectives on technologically led sustainable manufacturing.

Planetary Challenge

The consumerist aspirations of China, India and Brazil have dramatically accelerated our exploitation of natural resources. The 21st century has opened up the idea of progress based on consumption to a billion more people, a decadent planetary lifestyle that we cannot afford in the long term. Despite a growing awareness of environmental concerns, our actions are slow and our thirst for consumption is overwhelmingly more powerful that our eco-minded endeavours.

> There are many 'optimists' who argue that the world could support double its human population ... but I have not met anyone who seriously argues that the world could support 12 times its current impact''. (Diamond, 2006, p.118)

Climate change, oil depletion, water stress, the destruction of natural habitat, soil erosion, overfishing ... all the signs that can lead to a societal collapse are there. And societies do collapse: Jarred Diamond describes 17th Century Easter Island as an example of a society that destroyed itself by 'overexploiting its own resources' (p.495). The inability of the various Easter Island clans to find ways to address the over-exploitation of their forest meant that they irreversibly destroyed the environment they depended upon to survive. This led to the rapid decline and collapse of a society that had previously flourished. This makes it a powerful analogy for our current world situation: our island is our planet, and we only have one. Yet we are consuming our natural resources as if we had several Earths at our disposal. It seems we are on the same path as Easter Islanders, but with an exponential growth of population to make matters worse. 'Moderate UN scenarios suggest that if current population and consumption trends continue, by the 2030s, we will need the equivalent of two Earths to support us' (Retrieved from http://www.footprintnetwork.org). As argued by Diamond:

> Even after a society has anticipated, perceived or tried to solve a problem, it may still fail for obvious possible reasons: the problem may be beyond our present

> capacities to solve, a solution may exist but be prohibitively expensive, or our efforts may be too little or too late. (p.436)

So, we understand the risks of depleting and damaging the resources we depend upon. We have also developed some effective, alternative green technologies, but we seem unable to act collectively and responsibly. The failure of the COP 17 Climate Change talks in Durban in December 2011 demonstrated once more how difficult it is for world leaders to agree on responsible ecological legislations that could safeguard our future. As designers we too have a responsibility to conceive and design sustainable future habitats and products. The Biolace project is inscribed in this context and aims at exploring emerging living technology as a potential radical solution for the textile industry.

The sustainable impact of the textile industry

A complex network of large scale agricultural units, oil-based fibre production, chemical dying and finishing manufacturing relying on petro-chemistry, the textile industry is responsible for contributing to soil erosion, water pollution, large scale CO2 emissions, waste and child labour. According to William McDonough & Michael Braungart:

> The industry that launched the Industrial Revolution has long illustrated some of its most notorious design failures. About one half of the world's wastewater problems are linked to the production of textile goods, and many of the chemicals used to dye and finish fabrics are known to harm human health. Often, the clippings from carpet or fabric mills are so loaded with dangerous chemicals they are handled like toxic waste, while the products made from these materials are considered safe for use in the home.' (Retrieved from http://www.mcdonough.com/writings/transforming_textile.htm)

Nevertheless, we are producing more and more of these textiles. The global production of fibres has steadily been increasing in line with global population growth. In 2009:

> Global fiber consumption increased 4.2 percent up to 70.5 million metric tons (tonnes). Man-made fiber consumption rose 4.0 percent to 44.1 million tonnes, and natural fibers netted an increase of 4.5 percent up to 26.4 million tonnes. The average fiber consumption per head is estimated at 10.4 kilograms based of a world population of 6.8 billion people. (The Rubb Report, 2010)

With the looming oil shortage and the growing need for land for food production, how will the textile industry provide for a further 3 billion by 2050? Most worryingly, if we are to believe the United Nations Department of Economic and Social Affairs' world population growth predictions for the next 300 years, we need to plan for the worst case scenario: a population of 36.44 billion in 2300 (2004, p.84, fig. 54). How much longer can we perpetuate the model of production set out by the industrial revolution and epitomised by the globalisation of economic exchange? It is crucial and urgent to go beyond the current short- and medium-term sustainable design and production strategies for textile manufacturing. Not only do we need to find means to produce enough for an exploding world population, but we need to do so whilst reducing drastically our impact on our natural resources. A brand new type of manufacturing is required. As Kevin Kelly argues,

> We address the problems of tomorrow not with today's tools but with the tools of tomorrow. This is what we call progress. (2010, p.101)

In this context, could living technology provide a new set of tools to sustain our future world population, without damaging or over-exploiting our natural resources? More specifically, could biomimicry principles combined with synthetic biology lead to a new perspective on manufacturing?

> If we go on as we are, it'll be very difficult to sustain things. But we won't go on as we are. That's what we never do. We always change what we do and we always get much more efficient at using things - energy, resources, etc. (Bailey, 2009)

The *Biolace* project investigates the potential of synthetic biology for textile mass biofabrication for the years post 2050, when living technology is predicted to be more mainstream. The following section will provide a brief overview of how biomimicry principles enabled by emerging synthetic biological tools could radically change the way we design and produce future textiles.

21st Century: The Bio Revolution

Biomimicry

> Biomimicry (from bios, meaning life, and mimesis, meaning to imitate) is a design discipline that seeks sustainable solutions by emulating nature's time-tested patterns and strategies, e.g., a solar cell inspired by a leaf. (Retrieved from http://www.asknature.org, September 2011)

The field of Biomimicry emerged in the 1960s and has since become ever more prominent as a potential model for sustainable growth. Benyus advocates that we need to produce like nature does, at ambient temperature, without emitting toxic gas, poisoning our water stores and depleting our energy resources.

> Life can't put its factory on the edge of town; it has to live where it works. As a result, natures 's first trick of the trade is that nature manufactures its materials under life-friendly conditions.' (Benyus, 1997, p.97)

Nature provides the ultimate model of sustainability where there is no waste, only nutrients, where fabrication happens quietly by actuating sophisticated networks of responsive and genetically programmed living molecules that have been optimised over nearly four billion years. Prior to the mid 20th century, imitating nature was a question of aesthetic and engineering aspirations limited by our capacity to understand nature's operating system at the nano level, as well as by our limited ability to shape interconnected materials on that scale.

> While the human engineer instinctively reaches for metals to heat and beat into shape, nature goes for proteins that are grown inside living cells at body temperature. A single protein molecule is made from hundreds of thousands of smaller component molecules, virtually all of which have to be in precisely the right place to work. (Forbes, 2006, p. 5)

Parallel to the field of biomimicry, the emergence of nanotechnology in the 1960s has led to the development of tools and materials that can be controlled at a nano level, thus making it possible to mimic nature on its own scale. Today, genetic engineering, synthetic biology and the study of complex systems have enabled us to transcend nature and to 'create things that evolution never achieved' (Forbes, p.1). The convergence of these different fields of science challenges our understanding of biomimicry. In this context, I put forward three different approaches to exploring and applying the principles of biomimicry.

- The 'Bio-Muse' Approach: inspired by nature's mechanics, we can imitate nature's principles by using conventional technologies. For instance velcro mimics the bonding and de-bonding material behaviour of a seed, but is produced by conventional manufacturing systems with all their limitations in terms of sustainable production.

- The ‘Bio-Harnessing’ Approach, (Benyus speaks of ‘biologising’ the design brief): translating nature’s alchemy by harnessing biological functions to fit a specific purpose and understanding how nature would tackle a given problem in order to apply this principle e.g. cleaning water by means of a vegetal ecosystem as opposed to using harsh chemicals.

- The ‘Bio-Hacking’ Approach: hacking nature by re-engineering biological processes and using the principles of self-assembly and self-replication to re-programme biological parts and create new living organisms so that they can perform a predetermined specific function, thus creating new synthetic life. This is the field of synthetic biology, creating programmable living matter from the ‘bottom up’.

It is the latter approach that this paper examines and the following section examines new biological fabrication tools and principles.

Synthetic Biology: Re-Programming Life

Until very recently, biologists have been observers. Their main focus has been to dissect biological parts and to study living organisms so as to understand the rules of life outside (in vivo) or inside (in vitro) the laboratory. Synthetic biologists are now in a position to code and re-programme life, and are beginning to create artificial living matter from scratch, they are on the verge of revolutionising the way we conceive, design and produce. For this, they are simply using what has become the main alphabet of the century: A (adenine), T (thymine), C (cystosine) and G (guanine) together with the 1s and 0s of our computer programming world. The Craig Venter Institute is a leader in the field of studying and analysing digital biological data. Venter states that:

> In essence, scientists are digitizing biology by converting the A, C, T, and G’s of the chemical makeup of DNA into 1s and 0s in a computer. But can one reverse the process and start with 1’s and 0’s in a computer to define the characteristics of a living cell? We set out to answer this question. (Retrieved from http://www.jcvi.org, accessed September 2011)

In May 2010, the Venter Institute announced the creation of the first self-replicating synthetic bacterial cell, achieving a major breakthrough not only in understanding and decoding this biological alphabet, but in controlling it. We can now speak the language of life. In this new bio-digital world, bacteria become manufacturers, and proteins become tools. DNA is the digital code that enables us to boot up or reboot a cell as one would do with a computer. 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.

Living Technology

> Living Technology (LT) as we see it, is a central part of what the US National Science Foundation (NSF), the US Department of Commerce (DOC), and the European Commission (EC) have termed Convergent Technologies (CT), technologies which the US and EU believe will have a very large socio-economical impact in 20-30 years. Convergent Technologies are defined as the technological results of the emerging synergies from the nano-bio-info-cognitive (NBIC) knowledge production. (Retrieved from http://flint.sdu.dk/index.php?page=living-technology-background, accessed September 2011)

Living Technology will radically challenge the way we design and consume products and question the very nature of the design and manufacturing processes. The implication on disciplines such as textiles are of huge consequence. Instead of crafting textiles, we can now effectively craft programmable smart living molecules from the bottom up. One key example is the quest to synthesize the qualities of spider silk. In 2002, Nexia Biotechnologies announced the successful production of spider silk derived from the milk of genetically engineered goats. Only eight years later, synthetic biologists managed to take artificial silk production a step further:

> Dr Chris Voigt of UCFS announced in 2010 the successful genetic engineering of the bacteria e.coli which is programmed to produce spider silk protein at ambient temperature. (http://www.technologyreview.com/biomedicine/25922/page1, accessed September 2011).

Prof Kaplan of Tuft University is investigating the potential for manufacturing where bacteria would effectively be the production line. Synthetic biology has just provided us with a new type of manufacture: genetically engineered bacteria. But this is only the beginning. We also now know how to combine the biological living world with inanimate matter.

> In 1997 it was discovered that, although proteins will never meet such substances in the living cell, in the laboratory they can bind to inorganic materials such as gold and silver ... the old division between living and non-living substances is breaking down - we can engineer hybrids between the two.' (Forbes, 2006, p.6)

A whole new panorama of possibilities is ahead of us, yet it is difficult to imagine how our everyday products could be enabled by such technology in the future. Designers will need to adapt and learn different tools to be able to understand how to work with these new living manufactures. They will have to grasp a brand new world where material and technology have effectively become one entity. The old-fashioned concept of using a technology as a means to transform a material will be redundant. These new living materials are also the technology that shaped them. And if we think that the introduction of computing technologies has radically changed the design toolbox in the last two decades, imagine what these new living materials will lead to. Living technology is about to re-map the material and technological landscape available to designers.

Future Digital Design

The control of the biological code matched by our knowledge of programming systems means that digital design, as we know it, can now be augmented by biological coding. The new toolbox is the Petri dish; the new programming design software is the DNA code. Until the late 1990s, the notion of digital design referred to 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? Very recently, gene design software has become available, such as 'Gene Designer 2.0' which according to the provider is:

> The ideal software developed for you to design sequences de novo without being limited by what nature can provide. Gene Designer 2.0 encompasses a complete and visually rich set of tools to bring your creative ideas to completion.' (Retrieved from https://www.dna20.com/genedesigner2 accessed January 2012)

The extraordinary alchemy of life is now available as biological engineering software. Too specialised for today's designers to understand, yet using a design language to address scientists and enable them to bring their creative designs to fruition by hypothetically re-programming biological blocks. Fifteen years ago, I learnt how to code the HTML language to be able to design a website. Today, I have no need to understand HTML programming because I have at my disposal a range of design software such as Wordpress, or Adobe Dreamweaver that enables me to concentrate on the creative side, whilst the software edits the code for me. I can imagine in another few decades having access to a design platform that produces the associated sequence of biological blocks and digital code whilst I design the perfect hybrid plant that will produce metres of fabrics through its roots. The colours, the strength and elasticity of the fibre as well as the aesthetic of this bio fabric will have been designed and programmed with this hypothetical new software. This is one of the imaginary scenarios that the Biolace project explores. If, in a few years, designers need to learn such gene designer programmes alongside the more common design software, then the relationship between the design and the scientific worlds will need to become more symbiotic. Designers will not converse with manufacturers but with scientists who will create their new bio design in a test tube. They will visit hydroponic gardens to review the production of their next season collection of textile designs. Should these science fiction scenarios become a reality, the key will be to integrate a responsible ethical approach to designing this *'Brave New World'*[ii].

Biolace: Probing the Synthetic World

The BioLace Project

The *BioLace* project explores the intersection of biomimicry, design, textiles and living technology to generate new answers and to imagine future resilient design scenarios. Focused essentially on the potential of synthetic biology to unravel the mean to programme and control the morphogenesis in plants, *BioLace* anticipates bio fabrication and illustrates the hypothetical future manufacture of fabrics such as lace, produced by bioengineered plants. If we can create bacteria that produce biofuel, adrenaline or silk, we can imagine engineering plants to grow products, architecture and textiles. We currently grow plants to produce textile fibres such as cotton or nettle, but what if we can design and code a vegetal hybrid that biofactures a lace, a weave, a knitted textile? As opposed to using agriculture to grow natural fibres that subsequently need to be processed through a long chain of polluting and energy hungry industrial treatments before becoming a commercial cloth, could we cultivate plants that grow ready-made fabrics? Such a *'biofacturing'* process means we would harvest textiles instead of manufacturing them. We are not at that stage yet, but several labs around the world such as The Haselhoff Plant Lab in Cambridge are investigating the very beginning of the genetic control of morphogenesis in plant development:

> We are building a new generation of genetic circuits that incorporate intercellular communication, and could be used to generate self-organised behaviour at the cellular scale. These kind of circuits and cell-cell interactions play a key role in plant development and morphogenesis, and synthetic circuits will allow bold new approaches to reprogramming plant systems' (retrieved from http://www.haseloff-lab.org)

Biolace is particularly concerned with a hypothetical morphogenetic control of root systems for food crops. Imagine a tomato plant, which produces fruits in its branches whilst creating a lace with its roots. Such a multifunctional plant would contribute to both food and textile production simultaneously and represents the ultimate engineered hybrid. With the convergence of living and non-living matter, we could also consider adding smart responsive behaviours to these cultivated fabrics. Could we imagine a hybrid linen-chameleon plant that produces an intelligent reactive lace that changes colour and has the responsive properties of a chameleon's skin? Enriquez argues that:

> By reading and rewriting the gene codes of bacteria, plants and animals, we start to turn cells, seeds, and animal embryos into the equivalent of floppy disks ... Data sets that can be changed and rewritten to fulfill specific tasks ... We start deliberately mixing and matching apples and oranges ... species ... plants and animals.' (Enriquez, 2001, p.6)

Of course, this starts to raise serious ethical concerns, should we even consider the potential of these technologies? The alchemists of the future will control the fabrication of life, but will they also control death? Can we stop these new synthetic molecules, plants and bacteria from self-replicating and endangering existing natural species? The last section of this paper will expand on the risks and ethics of living technology.

Design as a Probing Tool

From a design perspective, synthetic biology and living technology imply an inherent understanding of biological and programming rules. It is crucial for designers to get involved at the onset of these technological developments so as to provide a link with societal and cultural needs as well as to develop an informed critical design discourse. Posing the right questions is as essential in science as it is in design. This project is currently ongoing and takes on four different design roles to examine living technology and synthetic biology:

- Design to translate and communicate complex scientific principles into accessible design scenarios and therefore facilitate an understanding of potential and mechanics of living technology

- Design to develop an imaginary synthesis of these technologies, in which biological, cultural, mechanical or artificial intelligent systems interact

- Design to translate pure science into tangible design applications

- Design to expose and challenge the potential risks of these technologies and stimulate a reflection on the ethical implications of designing with synthetic biology and living technology

The *BioLace* project is a family of design scenarios comprising a series of photographic fictions; design probes and animations that explore textile design and fabrication principles post 2050. It aims to question whether synthetic biology could turn our polluting industrial chemical textile manufacturing system into a safe ecological *biofacturing* system. Above all, it attempts to relocate the designer at the core of a scientific and technology led biological revolution.

Figure 1. BioLace, Design Probes, Series 1, 2010. Photo ©Carole Collet

From Industrial Revolution to Biological Resilience?

A Technogaian Future[iii]:
No matter what the future holds, we know for certain that new technologies will play a key role, it is up to us to identify which ones can lead to a sustainable way of life, one that copes with the population explosion without endangering the very natural systems we depend upon. There is a growing argument that 'Living Technology' can provide a viable low cost set of solutions to some of our environmental problems. With the industrial revolution, technology assumed the role of fostering 'progress' in terms of economic growth and living standards. 'William Nordhaus would say that at least 50 percent of economic growth in the 20th century is because we're using better recipes, which is better technology.' (Retrieved from http://reason.com/archives/2009/01/07/chiefs-thieves-and-priests/singlepage). Can living technology achieve 'ecologically improved recipes? Is Synthetic Biology the next Holy Grail? Rachel Armstrong argues that 'the process is more like gardening than maintaining a car engine … these technologies have the potential to be environmentally responsive and inherently sustainable." (Bedau, Guldborg Hansen, Parke, Rasmussen, Living Technology 5 Questions, Armstrong, 2010, p.3.) To aim for a resilient society inspired by nature and empowered by sustainable technologies means to achieve the development of ecological principles such as 'whole system thinking', 'co-evolution' and self-reproduction.

> 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 adaptation and ongoing creativity. There is increasing need for technology that has these features; such technology could be said to be literally 'alive' … so the future of intelligent, autonomous, automatically adaptive systems will be living technology.' (Bedau, Parke, 2009, p.7)

The question is who controls living technology?

Ethics and Risks of Living Technology
Living technology and synthetic biology present us with materials and technologies that can have the properties of life. They can self-replicate and propagate.

> 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 – nanorobots - could soon be taking over the planet.' (Greenfield, 2003, p.5)

The issues here are complex: not only does creating life in a laboratory raise moral and ethical concerns but, as with most technologies, one of the key questions is who is in control? Will bio-nano organisms take charge regardless of what they were programmed to do? Will they outperform and evolve into uncontrollable and uncatchable molecules? In 1986, Drexler alerted us on the potential risks:

> "Plants" with "Leaves" no more efficient than today's solar cells could out-compete real plants, crowding the biosphere with an inedible foliage. Tough omnivorous "bacteria" could out-compete real bacteria: they could spread like blowing pollen, replicate swiftly, and reduce the biosphere to dust in a matter of days' (Drexler quoted by Joy, 2000, retrieved from http://www.wired.com/wired/archive/8.04/joy_pr.html)

The ability to develop mechanisms of control by programming these synthetic cells to survive in only specific conditions or to self-destruct once they have performed their function can provide some level of control. But can it be enough? A small programming mistake could have devastating consequences. 'This is the first moment in the history of our planet when any species, by its own voluntary actions, has become a danger to itself - as well as to vast numbers of others.' (Joy, 2000, retrieved from http://www.wired.com/wired/archive/8.04/joy_pr.html). The speed at which these technologies are developed is fuelled by competitive corporate companies and driven by profit margins, not the most reassuring environment to guarantee safe use and production of living self replicating molecules. This has led to a recent burst of governmental reviews and policies that attempt to define national and international ethical guidelines. Increased government funding in these areas will promote an increase in the level of public research and hopefully foster the development of a greater understanding of the risks and limitations of living technology for our future selves and our planet.

Conclusion

In the past decade we have witnessed a sudden convergence of scientific fields, which has the potential to revolutionise the way we produce medicine, energy, and raw materials. Living Technology harnesses the knowledge of genetic engineering, synthetic biology, information systems, nanotechnology and artificial intelligence. The ambition to mimic nature's operating systems and to fabricate like nature has become a reality. Synthetic Biologists are beginning to understand the code of life and are creating new programmable synthetic cells that have never existed until now. The current and forecasted environmental pressures and an exploding world population require effective short-, medium- and long-term alternative, green technologies. Living technology could be a means by which we can achieve a sustainable resilient society. But equally, this technology raises very serious and complex ethical questions. It is crucial that the design industry engages with these new emerging technologies to anticipate the pros and cons of this biological revolution and to position the role of the designer within this new scientific landscape. The current BioLace project explores the potential of this new alchemy by developing future design scenarios to understand, imagine, and question what impact synthetic biology could have on the textile industry. Above all, this project intends to examine the values and risks of Living Technology as a potential means of developing truly sustainable textile manufacturing. And indeed, what will become of the designer when and if we move from manufacturing to biofacturing?

Notes

i The term "Living Technology" was coined by Mark Bedau, John McCaskill, Norman Packard and Steen Rasmussen, in New Mexico 2001

ii Title borrowed from Huxley, 'Brave New World', first published in 1932

iii http://technogaian.com/ (accessed September 2011). Technogaianism (a portmanteau word combining "techno-" for technology and "gaian" for Gaia philosophy) is the stance that emerging technologies can help restore Earth's environment, and that developing safe, clean, alternative technology should therefore be an important goal of environmentalists.

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