# Art from synthetic biology

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# Art from Synthetic Biology

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**DECLARATION**

I, Howard Boland, confirm that the work presented in this thesis is my own. Where material has been derived from other sources I confirm that this has been indicated in the thesis.

# Abstract

'Art from Synthetic Biology' is a practice-based research investigating the use of bio or living matter (as normally explored by the biosciences) in art production. The research employs novel standardisation processes in synthetic biology to develop genetic characteristics in bacteria that can expand understanding of, and approaches to art-making using living materials (bio art).

The research reflects on how artists can employ methods from the biosciences that focus on the plasticity of living matter; what critical issues are thrown up through such approaches and what are the potentials for art practice. Biological art practices have sought to employ living material by negotiating aesthetics, ethics and cultural meanings with emphasis on metaphorical aspects rather than biological significations. By taking into account biological processes, the research examines the role art practices can play in brokering understanding of 'life' in non-human biological systems and what sort of interfaces can be built to enable access to such knowledge. Through an immersive laboratory practice that integrates evidence-based scientific methods, the research offers a framework that conceptualises approaches for making bio artworks by delivering a set of methods and outcomes. Further, these methods provide approaches for achieving and critically evaluating art-science practices. As a material practice, it employs molecular interfaces to transform intangible processes into experiences that bridge human and non-human living systems.

Finally, the research considers how artists can overcome challenges of exhibiting living synthetic biology artworks. The practice, thus, identifies an existing gap in displaying artworks involving genetically modified organisms (GMOs) within a UK-specific context and established a regulatory framework permitting GMO artworks to be formally shown in UK for the first time.

# Acknowledgements

This research was made possible by my supervisors, Dr Tom Corby and Dr Mark Clements, through their willingness and patience in pushing into the uncertain boundaries of art and science. Since the beginning, Tom helped direct its path by breaking through the institutional and disciplinary barriers. In the biosciences we had the great fortune of meeting Mark who came on board and was instrumental in steering the research through this ramified knowledge domain. Organising an immersive laboratory practice was no easy feat and involved considerable costs and overheads, and I was humbled by how my supervisors went out of their way to facilitate this possibility. Dr Peter Goodwin, the Director of Research at the School of Media Art and Design (MAD), and Professor Jane Lewis, the Dean of the School of Life Sciences, also helped put a spin on the academic machinery and made available the necessary resources for this undertaking.

Funding was obtained through a doctoral scholarship from MAD and I am thankful to the selection committee who saw this research's potential at early stages. With Tom's help and the insightful inputs of Professor Jeremy Till, this research also obtained a doctoral award from the Arts and Humanities Research Council (AHRC) and I extend my gratitude to its selection committee. As the research shifted from production to public dissemination, travel grants from the school of MAD made it possible to present in conferences and exhibit the research outcomes internationally.

The path of a doctoral research does not come without unforeseen events and I am indebted to Professor Joram ten Brink, who in Tom's absence helped push the research through its transfer phase and Dr Marquard Smith who provided temporary supervision until Tom's return in June 2012. I was delighted to have Tom back and his agile navigation of language through domains of art and science helped land this research.

Working in a laboratory environment alongside scientists is an intense experience and a close knitted community. I offer my sincerest thanks to the members of the laboratory for taking me in and being supportive through my material struggles. In particular, Dr Anatoliy Markiv for insightful suggestions and Dr Armaghan Azizi whose balanced laboratory skills I tried to adopt. I extend my gratitude to all the laboratory technicians that provided insights, materials and

routines. Specifically, Neville Antonio whose inventive fermentation skills opened me to exciting opportunities and Dr Thakor Tandel's resourcefulness in finding treasured esoteric ingredients.

The research was also able to participate in several competitions. I had the pleasure of competing with a team of PhD science colleagues at the Yes Biotechnology competition. I also had the privilege of working with the University College of London (UCL) through Darren Nesbeth who invited me to participate in the UCL iGEM team in 2011 and as an advisor the subsequent year. I also enjoyed starting up the Westminster iGEM team in 2012 as an advisor and instructor. For the opportunity to partake in these competitions and the stimulating discussions, I thank all students, researchers and organisers.

To all the institutes and researchers who kindly donated material and provided invaluable advice, I have duly noted your names inside this thesis.

The final period of exhibiting GMOs opened fascinating discussions and I would like to thank the stakeholders for their input to this debate: Candy Meroe (Wellcome Trust), Dr Daniel Glaser (Wellcome Trust), Gina Czarnecki (Fact), Jens Hauser, Professor Marina Wallace & Dr Caterina Albano (Artakt), Michael John Goreman & Lynn Scarff (Science Gallery, Ireland), Nathan Cohen (Central Saint Martins College of Art and Design), Oron Catts (SymbioticA, TC&A) and Robert Devcic (GV Art). Particularly, I would like to thank Paul Sankey at the Health and Safety Executive for his advice in enabling this prospect.

Above all, I thank Dr Laura Cinti, who has been integral to the research personally, professionally and academically. Laura has been a source of inspiration since the start of this research. It was with Laura I entered into the field of art and science, and founded the collective C-LAB, where much of our activities are disseminated. Laura obtained her doctorate in 2011, and our academic research has naturally become intertwined through discussions, motivations and by being partners in life.

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# Chapter 1
# Art from synthetic biology

## 1.1 Introduction

The reason for undertaking this research was to explore through art practice the opportunities afforded by the plasticity and component-like qualities of living matter as revealed by recent advances in the biosciences.

Bio-scientific practices include the systematic investigation of intangible life processes on levels pertaining to cells, proteins and genes, their interactions and expressions. Making such material malleable has been a subject for the biosciences and provides a great deal of promise. Captivated by such prospects, artists have responded through an array of thematic contributions using a variety of traditional and contemporary media. A small but growing community of artists (or bio artists) have also sought to explore living matter as an artistic media itself. However, this approach requires specialised skills and access, leaving many artists reliant on scientific collaboration. The resulting effect is that materials have often been 'borrowed' from the sciences and appropriated into an artistic context where they serve metaphorical, hermeneutical and speculative roles. A few artists have adopted scientific methods in a limited way, but still these outcomes tend to address metaphorical concepts[1]. This research attempts to attend to this issue (and differentiate itself from previous work), by grafting a scientific methodology onto artistic practice in a way that employs rigorous laboratory-based methods within a research framework that makes such approaches available and portable via documentation, exhibition and analysis.

Thus, this practice first and foremost explores how artists might work with the processes of synthetic biology to: explore bio matter as a media through making artworks and exhibiting it; explore how bio processes might be made public; and develop experiences of invisible bio processes in sensory forms. In doing so, the research seeks to bridge the disciplines of art and science in order to develop hybrid methods for the field of inquiry.

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[1] For instance, in Eduardo Kac's *The Eighth Day* (Kac, 2001), the artist staged several transgenic animals and plants expressing green fluorescent proteins in a terrarium. Undisclosed are the reasons for these organisms expressing an iridescent colour, rather the spectacle serves a symbolic purpose as an iconography or metaphor for an alternative and transgenic nature.

## 1.2 Background to the research

A conceptual and methodological platform to negotiate these crossovers had already been established through a Masters in Digital Practices (2002) and years of working as a professional programmer on creative projects. However, most of this background knowledge rests on a specific interest in art and biotechnology that began by co-founding the art-science collective C-LAB (2003)[2]. Through C-LAB, my practice has had an ongoing engagement with critical and contemporary amalgamations of bio and electronic art.

In following the 2005 international Genetic Engineered Machine competition (iGEM)[3], it seemed to me that a potential was emerging for artists to both access and explore new developments in genetics through synthetic biology. In 2008, I began to seek out tangible ways of engaging with the field, first by partaking in a two-day key conference on synthetic biology and its societal impact (The Royal Society, 2008)[4] and subsequently by discussing with organisers[5] of iGEM how to participate in the competition as an artist, which at the time was a novel approach. Finally, in 2009 this material was gathered into a proposition to conduct an artistic study in synthetic biology on the programmability of life.

## 1.3 Research questions and objectives

The research is guided by four questions:

(RQ1) How can artists assimilate the recombinant (i.e. plastic) affordances of bioscience to art production and what critical issues are thrown up through such approaches?

(RQ2) What role can art practices play in brokering understandings of 'life' in non-human biological systems (e.g. bacteria)?

(RQ3) What physical and biological interfaces can be devised to enable access to this knowledge?

(RQ4) What can be learnt from exhibiting living synthetic biology artworks and how are regulatory frameworks negotiated?

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[2] C-LAB was co-founded with Laura Cinti, (Boland and Cinti, 2011).

[3] Organised by Massachusetts Institute of Technology (MIT) and involving undergraduate and postgraduate students and the deliberation of protocols, tools and the materials produced through open source platforms.

[4] Hosted at the Royal Society with over 120 leading academics, policy makers and stakeholders from the UK, USA and Europe including: Pamela Silver (Harvard Medical School), Jason Chin (Medical Research Council Laboratory of Molecular Biology) and John Glass (Craig Venter Institute).

[5] Personal Communication with Silver, Randy Rettberg and Cowell Mackenzie.

The following objectives were set to address the research questions:

1) Investigate new standardisation processes in the biological sciences to develop artworks, methods and approaches for artists employing bio matter;
2) Deepen understanding of the wider socio-cultural implications of biosciences through visual arts practice via the public display and discussion of artworks;
3) Develop interdisciplinary methodologies through working in laboratory contexts and engaging with scientific practices and cultures on a daily basis (thus contributing to debates concerning collaborative practices between art and science);
4) Explore how audiences gain access to art practices that employ bio-material to develop understanding of exhibition and public dissemination strategies of such work.

## 1.4 Overview of thesis

The thesis lays bare approaches to making bio art, accounting for the field's background, outlining its specific material challenges, describing methods of production and ways of developing outcomes, and critically reflecting on how such works might be exhibited in public settings.

Subsidiary information such as appendices, glossary of terms and references are accompanied at the back of this thesis. A DVD provides additional videos and an extensive set of documents that can easily be accessed in digital format but would be excessive to include in printed format.

In addition to the introduction and conclusion, this thesis is organised into five chapters.

Chapter 2 introduces the field of bio art and its relationship with the biosciences. It debates the taxonomy of terms and definitions surrounding such practices, and identifies challenges of production and staging of bio artworks.

Chapter 3 examines the theoretical background of bio art. It reflects on the field's shift from thematic to material investigation by considering how metaphorical and biological processes are mediated in the bio arts. The use of living matter as art also opens ethical questions and the research debates a series of positions useful in negotiating such dilemmas.

Chapter 4 deliberates on choice and use of methodology in this research. It argues why an immersive laboratory practice was appropriate and discusses its institutional arrangements. To adopt an independent practice, it suggests learning mechanisms and outlines a framework of methods appropriated from synthetic and molecular biology. As a particular synthesis of art and

science practice, it discussed how evidence-based approaches were needed and supported through documentation, tools and reflection.

Chapter 5 centres on the development of research outcomes. A series of experiments and artworks were developed using genetic engineering and synthetic biology by drawing on foundation of methods in Chapter 4. The chapter discusses how these works addresses the research inquiry (its particular synthesis of art and science), and reflects on experiences of an artist working in a laboratory environment.

Chapter 6 deals with the challenges of exhibiting these artworks, dissemination through public debates and participation in activities relating to synthetic biology. Since many of the outcomes involve GMOs, it suggests how specific regulatory frameworks can be negotiated to exhibit such works.

## 1.5 Methods

Even for trained scientists, the invisible nature of bio-material processes, lack of immediate feedback, multitude of parameters and unknowns produces many practical and theoretical difficulties. For artists to work in this area requires a significant intellectual investment - to an extent 'become a scientist'. An approach common in the bio arts involves finding willing scientists to perform manipulations, however this carries the risk of leaving artists with superficial understandings of the material they are dealing with. The recent emergence of 'do it yourself' (DIY) bio practices have offered an expanding arsenal of DIY tools and interesting insights into technological interfaces, but has had limited scope in getting us closer to biological processes and ends up situating the living at a distance (i.e. the focus is on the instrument and what it can do, rather than the capacities of the living[6]).

In this research, I have sought an opportunity to deepen engagements with the biosciences through experimental approaches that can open new understandings of the relationships between art, science and life processes. This research attempts to dip beneath metaphor and thematic concerns and get intimate with the material. What comes out is art intertwined with science and I believe this better addresses what bio art can be - that is, an art form involving the

[6] Artist Andy Gracie has developed a range of tools and instruments to explore this aspect artistically, such as *The Quest for Drosophila titanus* (Gracie, 2011). There are also communities such as Hacketeria (hacketria.org) dedicated to these activities.

transformation of intangible bio-scientific processes into concrete sensorial experiences in the actual living presence of bio matter.

The daily practice was situated within a bioscience laboratory providing a wealth of useful insights to inform the theory. In Chapter 3, the research unpacks bio art as a practice moving from speculative to material strategies and suggests how this can be further deployed by tapping into biological processes and extended capacities in the living.

In Chapter 4 and 5 the use of specific scientific methods in the practice is described highlighting how the practice weaved artistic and scientific approaches. To situate the practice in a laboratory setting required institutional arrangements and establish learning mechanisms to adopt scientific methods. In Chapter 4, the practical constraints of working with often-invisible biological processes, evidencing results and visualising expressions over time are also addressed through various documentation methods. This provides insight into elements of the works and developmental processes. As a research process, the practical struggles through a laboratory engagement provided material for reflective discussions in Chapter 5 developing discussion of the investments into scientific skills practitioners need to undertake. Chapter 6 discusses how the research shifted from production to staging of artworks and involved a set of challenges arising from exhibiting GMOs that required the design of specific solutions which directly influenced discussions and findings. Exhibiting works from this research requires steps that were established both through formal documentation (supplied in the appendices, such as ethics approval and agreement with Health and Safety Executive [HSE]) and discussions with stakeholders. The dynamics between practice and theory was therefore such that much data emerged from the practice and became contextualised into a theoretical structure and model of practice.

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# Chapter 2
# Bio art: roots, literature and debates

## 2.1 Introduction

This chapter aims to deliberate on the loosely coupled field of bio art. There are, as will be evident in Chapter 4 and Chapter 5, multiple aspects situating this practice-based research within bio art: (1) it manipulates living bio matter at levels pertaining to cells, bacteria, genes, plasmids and proteins; (2) involves deep immersion into laboratory and biological practices; and (3) engages artistically, through scientific approaches, with the emerging field of synthetic biology. These factors position this research well within the scope of bio art despite uncertainties surrounding the field.

No single body of knowledge controls research in the area of bio art. As an emergent field, struggling to define itself amidst a limited set of artworks[7], bio art remains an unsettled but captivating subject. Dealing as it does with the biosciences (Section 2.2), efforts in recent years to tackle issues of access to such practices have increased activities. Dominant stakeholders involved in institutionalising bio art have attempted to formulate the field on the basis of their own practices, however it has been difficult to reach consensus on terminologies and subject boundaries (Section 2.3). Given its brief and sporadic history, bio art has only emerged as a field in recent years (Section 2.4).

The literature is varied but loosely connected and includes well-written editorials, essays, 'grey' literature such as exhibition catalogues, and online discussions. Only a few exhibitions dedicated to bio art have taken place and artworks in the field are frequently featured in new media settings. While there are no annual reviews on bio art, exhibitions featuring bio artworks are, in most cases, accompanied by symposia on the subject (Section 2.5).

With many adjoining areas, the subject boundary is slippery and to fully grasp the field there is need to account for the multiple perspectives using hybrid approaches. It is not within the scope of the thesis to give a detailed account of each adjoining subject area as this amounts to extensive research in its own right. However, a brief outline of the major debates is relevant as they affect the way we understand and approach the field.

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[7] In terms of artworks actually employing bio matter as a media.

As bio art deals with living matter from a post-biological perspective (a concept understood through multiple parameters[8] but taken here to mean new material conditions emerging from modern biotechnologies such as tissue engineering, genetics and nanotechnology), there has been a schism between artists approaching the field from thematic and material grounds. Such differences, discussed in section 3.1, can be understood by looking at representational depiction and material use of bio media and provides a backdrop to how the field has defined itself through material approaches. Finally, section 3.2 outlines how the material uses of bio media problematises the field ethically. A plurality of ethical positions may be found amongst bio artists, however debates suggest a need for artists to remain vigilant against anthropomorphic uses of bio media, that is, the mapping of cultural meanings onto living systems.

Whilst it is accepted that bio art has to do with biological matter or bio media, the process of manipulation at a specific level (e.g. genes) and towards artistic purposes suggests its subject boundary. However, neither the definition (below) nor the use of media remains unchallenged, as will be explicated in section 2.3 and 3.1.

> [Bio art] is first and foremost an ephemeral and process-based art of transformation *in vivo* or *in vitro* that manipulates 'biological material at discrete levels – be it cells, proteins, genes or nucleotides – creating displays which allow audiences to partake of them emotionally and cognitively' (Hauser, 2005: 185; Kac, 2007) and whose status is still largely unclear. (Hauser, 2006)

Bio art, as an interdisciplinary hybrid art practice, deals with knowledge processes that impinge on the biosciences in its post-biological status thus there is a need to provide a brief account of this broad scientific area.

## 2.2 The biosciences

The biosciences or the biological sciences, or simply biology, is the study of life and living organisms. The word biology comes from the Greek: bios – 'life', logos – 'knowledge' (Roberts et al., 2000: 1). As an enormous and rapidly developing subject, the biosciences involves many allied disciplines such as chemistry, physics, mathematics, geology and psychology (Roberts et al., 2000: 1).

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[8] Cybernetic writer and robotics pioneer Hans Moravec relates the concept to self-improving and self-thinking machines differently to our world of living things (Moravec, 1993: 5).
Artist and theorist Roy Ascott employs the post-biological to describe "the potency of new technologies [e.g. Telematic connectivity, the associative structures of hypermedia, virtual reality and artificial life] of mediation, construction and transformation in our understanding of consciousness and our perceptions of reality." (Ascott, 1997).

Given the sheer extent of the field, the biosciences remains a fluid term that glues together the temporal bioscientific areas dealing with the understanding and manipulation of life in a quest for knowledge and for the sake of society. There are numerous ways to account for its components such as dividing it into disciplines relating to either health (medicine) or applied biosciences.

Applied biosciences or applied biology is the application of the biological sciences to human affairs (Roberts et al., 2000: 9). An important area, and where this research and much of bio art situates itself, is biotechnology[9], which embraces 'all aspects of applied biology that has a technological slant' (Roberts et al., 2000: 9). Biotechnology adjoins many areas in the biosciences, however two definitions encapsulate the breadth of its activities, firstly:

> Biotechnology is the application of scientific and engineering principles to the processing of materials by biological agents to provide goods and services. (Bull et al., 1982)

And secondly, and more broadly, it could be said to involve:

> The manufacture of products by or from living organisms, usually involving bioprocessing. (Rader, 2008)

Both definitions include traditional biotechnologies and agricultural practices (such as the production of bread, cheese or wine), thus the term 'modern biotechnology' is sometimes applied to distinguish recent technologies and methods from the former. Figure 1 shows an internationally adopted convention staking out biotechnology beyond traditional practices.

Modern biotechnology builds on a series of innovations that for the purpose of this research will be delimited to the period after the discovery and characterisation of the molecule 'Deoxyribonucleic acid' (DNA) by American biologist James Watson and British physicist Francis Crick (Watson and Crick, 1953).[10]

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[9] Originally coined by the Hungarian engineer Karl Ereky (1878-1952) in 1917 to mean the use of scientific methods to produce products from raw material with the aid of living organisms (including husbandry) (Andrews, 2000: 22).

[10] Also instrumental to the elucidation of the DNA was the British biophysicist Rosalind Franklin and New Zealand born English physicist and molecular biologist Maurice Wilkins.

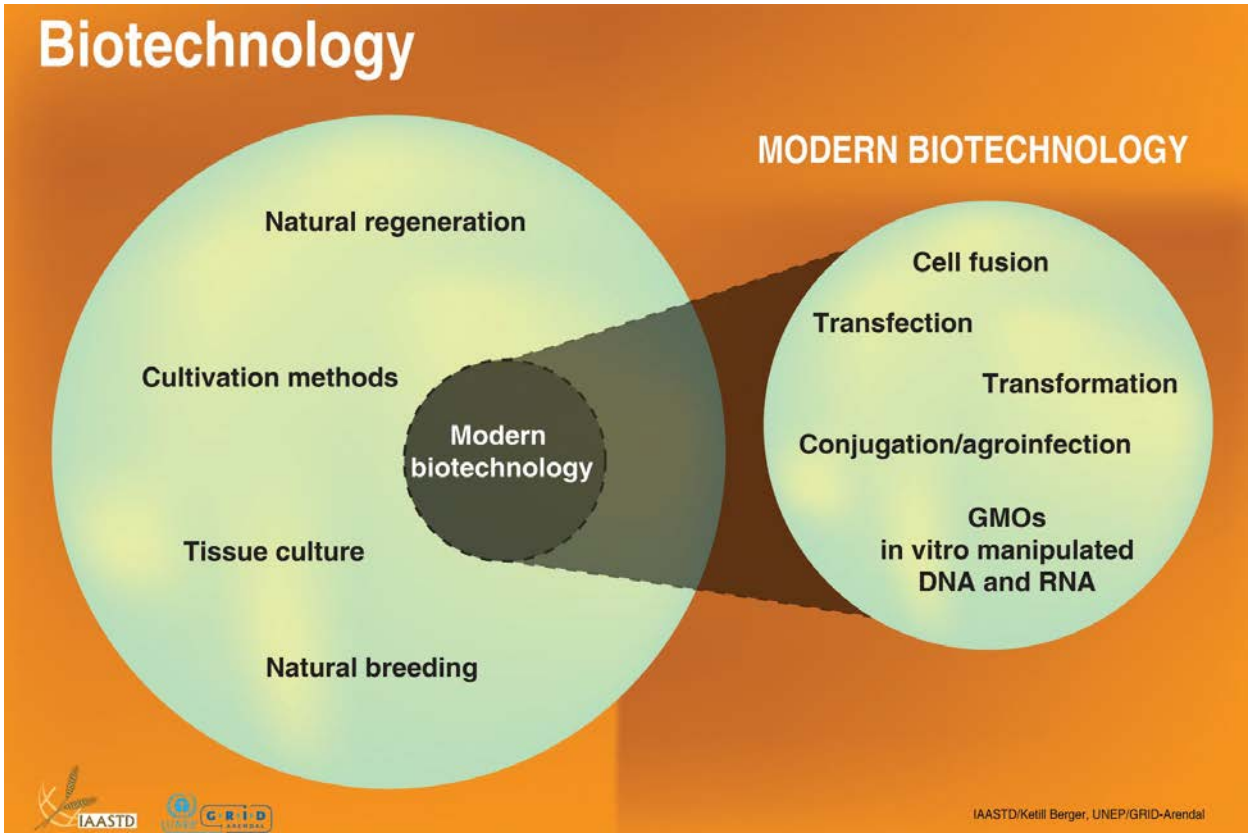


Figure 1: Biotechnology and modern biotechnology defined (IAASTD/Ketill Berger, UNEP/GRID-Arendal, 2008). Reprinted with permission from GRID-Arendal.

In recent years, biotechnology has dramatically increased our ability to transform life (Mosier and Ladisch, 2009: 3). Moreover, 'the greater understanding of life processes has also brought an increasing potential to control and exploit them' (i.e. genes are now routinely transplanted from one species to another) (Goldsmith and Zimmerman, 2001). These developments have opened the field to public controversies and generated fascinating but unsettling notions surrounding technology and life. Emerging areas of biotechnology, particularly 'synthetic biology' discussed in Chapter 4 and a focus of this research, implicates more radical interventions that can create synthetic life and utilise standardised genetic building blocks to fabricate living synthetic devices.

Modern biotechnology poses a post-biological paradigm by circumventing evolutionary trends governed by nature. Considerable international efforts have been put in place to achieve such possibilities including the 'Human Genome Project' (HGP) completed in 2003, the largest ever collaboration undertaken in biology mapping the complete set of human genes (Newton, 2004). The sheer volume and complexity of data generated through efforts like the HGP has made the biosciences dependant on developments in computation (e.g. DNA sequence analysis) and generated a hybrid field, 'bioinformatics'. Efforts have been motivated by concerns relating to

human activities such as; lack of food resources and growing population, need for alternative energy, major health threats and age-related problems (Figure 2).

Technoscientific[11] approaches to resolve such matters encroach on problematic scenarios as they involve radical (bio)technological interventions that open unprecedented ethical issues. Further, the biosciences involve the pharmaceutical-, health- and agricultural-industries of significant economic and political importance (Mosier and Ladisch, 2009: 3-10). This suggests a utilitarian 'neutral ground' of 'serving society' has been destabilised and become subject to pressure from stakeholders wanting to capitalise on investments. Whilst such issues seem removed from laboratories' daily research routines, they are undoubtedly shaping them.

Likewise, the public(s) is a major stakeholder in the biosciences even if a personal impact on the field seems remote. For instance, genetic discoveries are responsible for 'cultural factors because they dramatically impinge on our daily lives' (e.g. [1] legal systems – establishing identity, [2] our medical systems – gene therapy, and [3] historically - evolution) (Levy, 1996: 20).

Whilst the biosciences involve complex knowledge processes, it also problematises what it means to be human through intimate and invasive procedures. How this knowledge is disseminated affects our attitudes on many levels. This is also where art can play a significant role[12] through its ability to deliver empathic, reflective and provocative ideas:

> The very existence of some of the outcomes of biotechnologies brings into question deep rooted perceptions of life and identity, concept of self, and the position of the human in regard to other living beings and the environment. Art has a long history of dealing with these issues. (Zurr and Catts, 2003: 2)

For bio art, such notions are taken further in the sense that artists (and in some ways the public[s]) become immersed in the biosciences to scrutinise and retrieve a sense of ownership of what is at stake.

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[11] Coined by the Belgian professor of Philosophy Gilbert Hottois in 1984 to mean the role of science and technology in knowledge production through material networks (Hottois, 1984: 67; Carrier and Nordmann, 2011: 469-471).

[12] Art used as an instrument to engage people in certain agendas may become dubious when 'grafted onto the bureaucratic framework of a prototypical social service organization' (Harter et al., 2008: 425). How this impacts art dealing with knowledge processes such as bio art will be discussed in section 3.2.

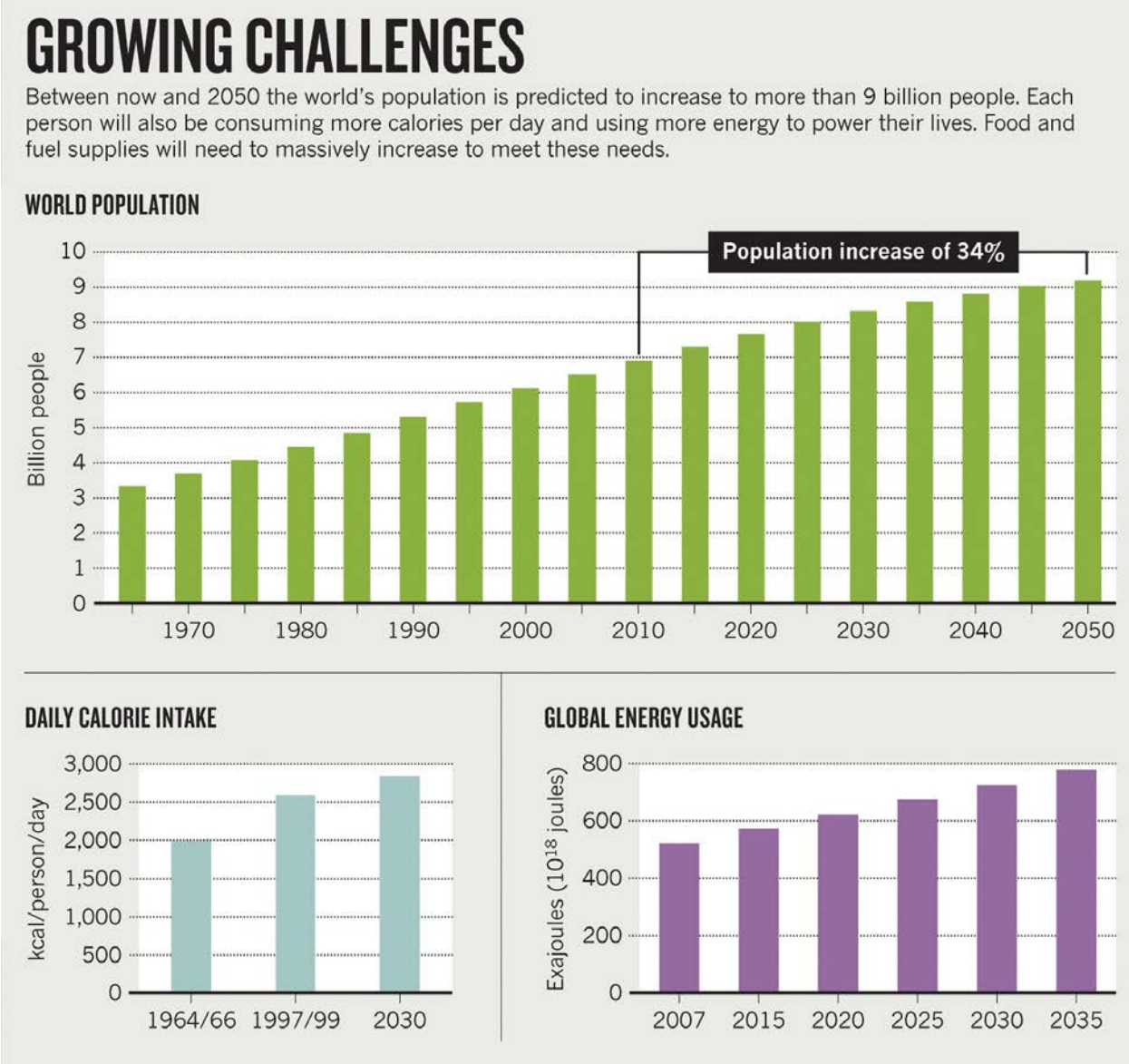


Figure 2: Growth challenges and predictions for 2050 (Graham-Rowe, 2011) adopted from 'How to Feed the World in 2050' (FAO, 2009). Image credit: Graham-Rowe, Duncan, 'Agriculture: Beyond food versus fuel', 'Nature', vol. 474, issue no. 7352, page 305. Reproduced with permission of Nature Publishing Group.

Further, artists' use of bioscientific tools and materials to generate cultural artefacts extend and disclose the way the biosciences 'weaves into the fabric of culture' (Campbell and Reece, 2008: 2). How artists find their place in the vast knowledge area of the biosciences, whether they are working together with scientists or exploring this field independently (as in the case of this research), suggests that there are many different readings of bio art depending on the type of engagement. As with the biosciences, bio art tends to be delimited by a similarly temporal and fluid subject boundary. Thus, before looking at the historical developments (Section 2.4), an overview of terminologies and defining characteristics of bio art is useful to understand the context bio artworks operate within and the background informing this practice (Chapter 4 & 5).

## 2.3 Bio art, terminologies and subject boundary

Bio art is by no means the only term used to define art practices involving the biosciences or living matter. Prior to the use of 'bio art', George Gessert, an artist and theorist in the field, employed the term 'genetic art'[13] to describe a broader area of artistic activities including his breeding practice:

> Genetic art, or art that involves DNA, includes a bewildering diversity of works. These range from paintings of chromosomes, and sculptures of the AIDS virus to installations about genetically engineered foods, land restoration projects, transgenic organisms, and breeding projects to recreate extinct species. (Gessert, 1999: 1)

However, 'genetic art' has also been understood as a specialised area requiring scientific expertise and involving:

> […] the actual or proposed genetic manipulation of living organisms and, to a lesser extent, the creation of synthetic deoxyribonucleic acid (DNA) molecules *in vitro* for the purpose of their presentation as art. (Davis et al., 2001: 1)

Outside art practices engaging with bio matter, 'genetic art' has been used to describe computer 'simulate[d] processes of life' (Gerbel and Weibel, 1993)[14] and was the title for the prestigious and 'visionary' (Wilson, 2002: 55) 1993 Ars Electronica Festival in Linz (Austria) hosted by the Ars Electronica organisation.

In addition to these multiple understandings, subsequent art practitioners have expanded the list of terms by creating words describing the specific manner they engage with bio matter (e.g. 'transgenic art' (Kac, 1998: 1) , 'moistmedia' (Ascott, 2000: 2), 'VivoArts' (Zaretsky, 2001), 'biotech art' (Hauser, 2003) and 'life art' (Bec, 2007)). How do these adjoining art practices relate to bio art?

Following Gessert, the development of multiple terms is indicative of specialised areas forming within bio art such as 'biotech art' and 'bio-ecological-art' (Gessert, 2010: introduction, xix). A definition of bio art, such as the one provided in section 2.1, must be broadened (beyond 'discrete levels') in the sense of becoming an umbrella term simply referring to 'art made of or by

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[13] Appropriated from computer art (Gessert, 2010: 120).

[14] According to the media theorist, curator and artist Peter Weibel, 'genetic art' is inclusive of: 'evolutionary art', 'biogenetic art', 'genetic engineering', 'algorythmic art', 'robotics', 'virtual beings' and 'artificial life'.

living organisms' (Gessert, 2010: introduction, xx)[15]. The internationally renowned artist Eduardo Kac, notorious for creating a portmanteau of compounding words as a strategy to establish artworks (Kalenberg, 2008), claims to have coined the term 'bio art' during a TV-interview in 1997 (Kac, 1997: 164; Kac, 2007: 164, 397). Its definition involving 'discrete manipulation', thus, can be seen as an expansion of the term 'transgenic art' (also coined by Kac):

> Transgenic art, I propose, is a new art form based on the use of genetic engineering techniques to transfer synthetic genes to an organism or to transfer natural genetic material from one species into another, to create unique living beings. (Kac, 1998: 1)

Kac's formulation situates bio art practices within the realm of modern biotechnology and moves conventional uses of bio matter (such as Gessert's breeding practices) to the fringe of its subject boundary. Many scholars have proposed that differentiating 'bio art' and 'biotech art' helps separate artworks employing modern biotechnology as a more specific area of bio art (Kac, 1998; Bureaud, 2002: 44; Tomasula, 2002; Hauser, 2005: 182). Further, the artist Ionat Zurr (of Tissue Arts and Culture Project [TC&A] and SymbioticA, see also section 2.5.3) noted in her Doctoral thesis 'Growing Semi-Living Art' that a too regimented use of bio art may exclude artworks by artists that have been instrumental in pioneering the field, such as Gessert (Zurr, 2008: 15). However, in order to 'limit' the subject scope of her thesis, Zurr suggested that bio art could be understood through the material employment of bio matter as opposed to traditional representation or depiction (Zurr, 2008: 18).

One attempt to organise the multiple terminologies around the subject was proposed by Pier Luigi Capucci, a new media theorist, through a widely cited diagram (Figure 3) that provides a taxonomy and subject boundary for the various specialised areas (Capucci, 2007a: 1-6). The diagram may be considered as an outcome of a discussion on the theme 'exhibiting bio art' held on the mailing list 'Yasmin', a network promoting collaboration in art, science and technology around the Mediterranean Rim, and has been informed and translated by Gessert (Capucci, 2007a: 5). In a question initiated by Jens Hauser, a leading curator, filmmaker and scholar on bio art: 'Do we need a "bioart definition"?' (Yasmin, 2005-: Message 48/86, 23th March 2006), Gessert stated that '[b]io art is art that is alive or has living components' without necessarily 'involving biotechnology or genetic change' but could include some forms of 'ecological' or 'land art' but should not include 'art that represents life' (such as depiction of chromosomes) neither

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[15] Although outside the scope of this discussion it is useful to note the correlation this has to 'animal art' which is the idea that many certain objects produced by natural phenomena resembles human artifacts (Guter, 2010: 8). Further, 'Animal Art' (curated by Richard Kresche, in Graz, Austria) was also the name of the 1987 exhibition featuring the work *Microben bei Kandinsky* (by Peter Gerwin Hoffman) often situated within historical context of bio art (Gessert, 2010: 116).

'computer simulation of genetic processes' but 'art that involves biotechnology in the broadest sense of the word' (Yasmin, 2005-: Message 51/86, 25th March 2006). Alongside Hauser, Gessert acknowledges that the only accepted representations are 'some kinds of documentation'. 'Transgenic art' according to Gessert is 'bio art that involves genetic engineering'; drawing on examples of Kac's work '*Alba* and most of Joe Davis works' (see Figure 3 below). As explicated, his own term 'genetic art' involves DNA in the broadest sense and crosses over to forms of representation and computer simulation that may include artificial life. Based on this, Gessert and Capucci suggest that bio art may be understood as an umbrella term. The division provided by the diagram (below) gives a useful overview of the overlaps and the existing artistic terrain explored at the time (circa 2006) but is also problematic in its lack of subject rigour. Further, it only takes account of a limited set of terms used by artists to describe their practices and does not position various branches of art involving biotechnology such as synthetic biology or nanotechnology.

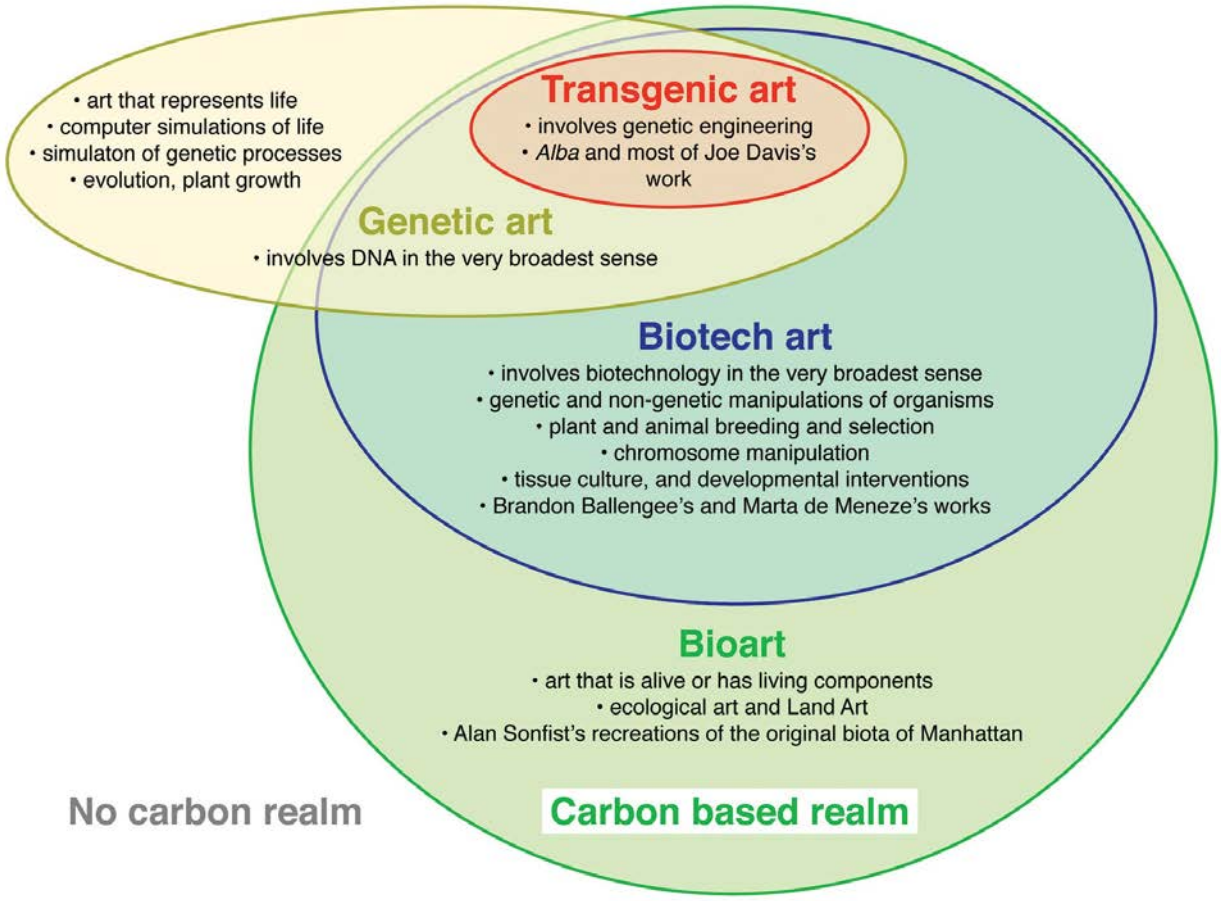


Figure 3: Capucci's grouping of bio art practices (Capucci, 2007b). Permission to reproduce this diagram has been kindly granted by Capucci.

The diagram highlights that bio art, despite focusing on the living aspect, must also question what is meant by life (i.e. What is life? Are viruses alive? How do we understand artificial life?). I will return to this topic when discussing my artwork *Stress-o-stat* (Section 5.7) by looking at the convergence between life and machine within the synthetic biology paradigm. Whilst the focus of bio art lies in its use of organic matter, it must also consider its relationship with extended notions of life. Capucci notes that the diagram (Figure 3) attempts to draw connection or provide a 'dialogue' between the organic and inorganic. In what he calls 'the second division of the living', Capucci proposes that artificial life is able to proliferate beyond the 'organic dimension' towards something more 'universal' and thus the question is no longer about the material but rather the 'instructions to regulate it'. The broader scope of life reflected in the diagram, as the non-biological living ('[non] carbon realm'), is thought to be disconnected from matter and therefore has 'greater freedom, greater possibilities and opportunities' (Capucci, 2007a: 3-4).

Bio art, broadly speaking, encompasses both art and science. However, there is also the area 'art-science' wherein bio art is regularly positioned as a specialised branch. Art-science works tend to be collaborative in nature through a division of work. Interaction between scientists and artists is often promoted as a positive activity and promises better funding opportunities. A general problem is that collaborations may become muddled by different disciplinary understandings. On the one hand, scientists use art as a means to reach a broader audience in the sense of (1) publicly highlighting aesthetic dimensions of their work, (2) a model for communicating science, (3) raising the scientist or institutional profile and (4) simply to adhere to certain funding criteria. For the art-science writer, Siân Ede[16], the use of artists to produce science 'propaganda' or 'prettification' is deplored (Ede, 2005: 3). For bio art, outside instrumental agendas, scientists' motivations are often vague:

> [T]he bio-art scientists tend not to attract media attention, either because they deliberately stay in the background or because they are ignored, so their intentions remain unclear. (Stracey, 2009: 496).

Artists' motivations can also be instrumental, where scientists are simply seen as (uncritical) technicians to realise artistic ideas. A further discussion on collaboration and a case for an independent practice is made in section 4.4 including methods for achieving this within the research practice.

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[16] Arts Director at the Gulbenkian Foundation (UK Branch) until 2012 who pioneered the Foundation's Art and Science programme from 1997 to 2009.

Apart from dealing with living matter, bio art is often distinguished from art-science in that artists engage with scientific tools, approaches and methods as an extended art practice (or as an art practice in itself). There are slippery boundaries, in particular where bio matter is used without necessarily involving living aspects, such as the 'emergent media' artist Paul Vanouse's electrophoresis DNA figures (Illustration 1) created by separating DNA fragments using electric current (Vanouse, 2006).

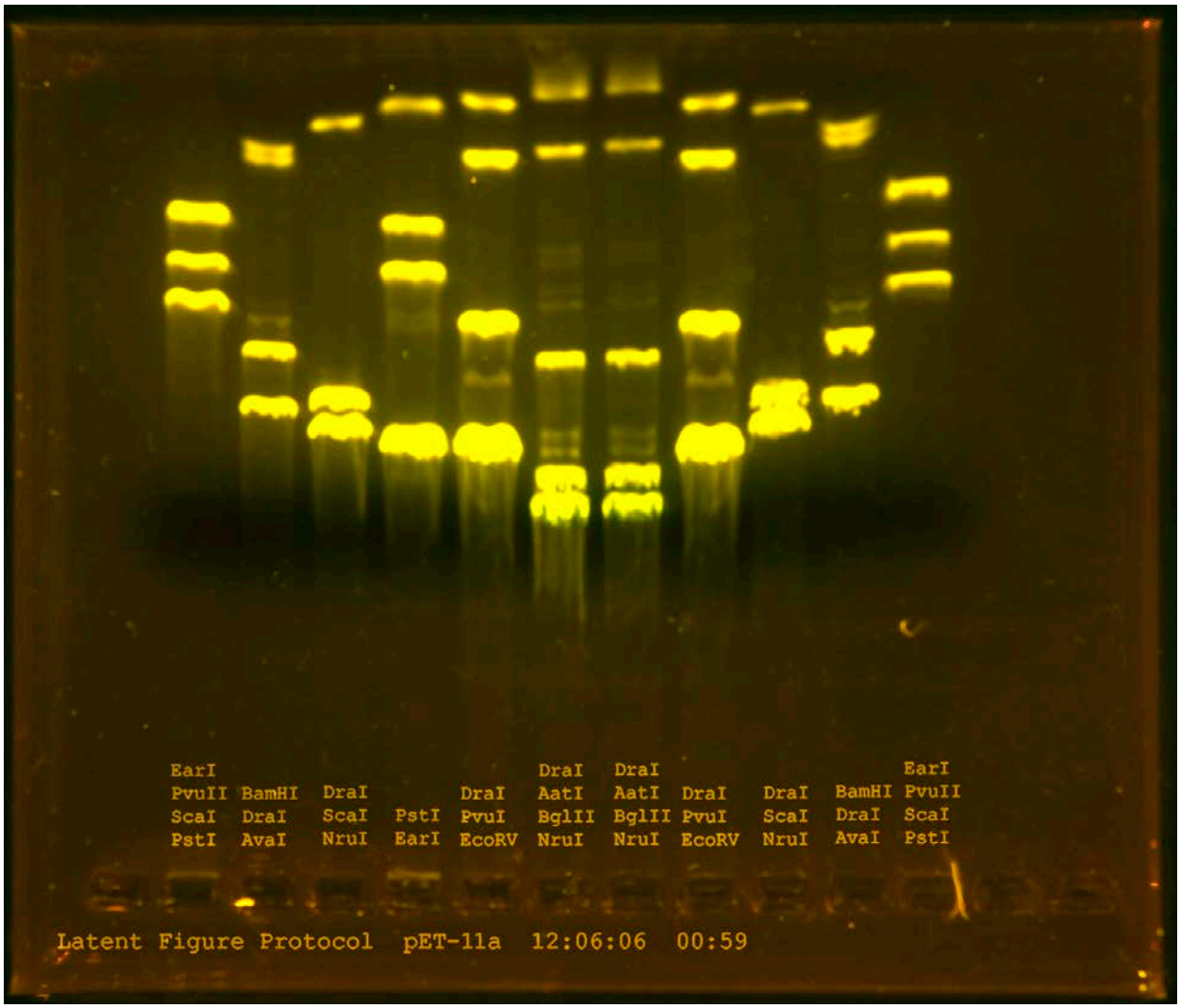


Illustration 1: Paul Vanouse, *Latent Figure Protocol* 2007-9. (Vanouse, 2006). Permission to reproduce this image has been kindly granted by Vanouse.

On the other hand, visuals produced by scientists are sometimes presented as art. 'Science art', as noted by Ede, are almost exclusively representational in the form of photographs or computer-generated models that highlight a particular type of aesthetics uninformed by contemporary arts (Ede, 2005: 3). Of historical note, are the germ paintings of the Nobel laureate Alexander Fleming, 'the first to use pigmented bacteria as an alternative to more conventional media such

as water colours or oils' (Adams and Hendry, 2002: 14) and more recently Ben-Jacob Eshel's colourful 'swarming social bacteria' has been presented as art (Eshel, 2008). Whilst scientific methods of obtaining visuals and forms of representation remain highly novel (Toulmin, 1953: 41) and captivating, mapped onto art they lack the necessary foundation to be understood under these conditions[17]. Added are the questions of intentionality, since such visuals emerge on the back of scientific experiments, and as argued by Zurr:

> We believe that BioArt, if it is anything, is not about representing the artistic side of scientists or the artistic side of the sciences in general. (Zurr, 2008: 17-18)

It would also be challenging for scientists to generate living organisms for aesthetic purposes alone as this falls outside utilitarian scientific agendas and prompts institutional ethical questions (Section 3.2). Despite this, there has been an ongoing exchange of organisms (natural or modified) between artists and scientists. Examples where organisms have been borrowed from scientists and exhibited or contextualised artistically are many (Kac, 1999; Kac, 2000a; Menezes, 2000; Kac, 2001; Barnett, 2008) and perhaps the most well-known is Kac's *GFP Bunny* (Kac, 2000a), Illustration 2.

Illustration 2: Eduardo Kac, *GFP Bunny*, 1999, 'Alba', the fluorescent bunny. Photo: Chrystelle Fontaine. Permission to reproduce this image has been kindly granted by Kac.

[17] Notably, the image entry for bio art on Wikipedia (a common public source for general research) presents the field through an photo of a 'germ painting' of fluorescing bacteria on a petri dish (Hoffmeier, 2007).

Whilst these exchange processes are sometimes problematic, they may involve transference of knowledge (e.g. procedures and techniques) and artistic modifications but also direct staging of scientific outcomes. By focusing on bio art through the material definition and including some of the broader notions suggested by Gessert, Capucci, Zurr, Kac and Hauser, we are now able to briefly look at how the field emerged historically and its key artists.

## 2.4 A brief historical overview

The first widely recognised artwork (Gessert, 1993: 205; Pinchbeck, 1995: 54; Gessert, 1999: 3; Youngs, 2000: 378; Davis et al., 2001: 1; Tomasula, 2002: 138; Anker and Nelkin, 2004: 66; Kac, 2007; Stracey, 2009: 496) that manipulated living matter on a genetic level was *Steichen's Delphiniums* (Illustration 3) by the renowned American photographer Edward Steichen (1879-1973). Exhibited at the 'Museum of Modern Art' (MoMA), New York in 1936, the giant delphinium blooms - the result of Steichen's mutagenic breeding practice - was described as 'breath taking' (Gedrim, 1993: 352-363).

Illustration 3: Installation view of the exhibition 'Edward Steichen's Delphiniums', MoMA, NY, June 24, 1936 through July 1, 1936. DIGITAL IMAGE © 2011, The Museum of Modern Art/Scala, Florence.

Whilst bio art has ties to 'ecological art', 'land art' and 'animal art' through artists such as Alan Sonfist, Joseph Beuys, Agnes Denes and Hans Haacke in the 1960s and 1970s (see Figure 3), it was only in the mid-1980s that a few subsequent artists explored the manipulation of biological matter as art. Of note, Gessert developed an Iris breeding practice[18] described in his paper 'Breeding for wilderness' (Gessert, 2002: 29-33) and the Massachusetts Institute of Technology (MIT) affiliated artist, Davis, embarked on a practice employing genetic engineering with his project *Microvenus* (Davis, 1986), where synthetic molecules of DNA were presented as art.

During the 1990s and 2000s, the number of artists had become significant enough to discuss these activities as a field. The following contributions are noteworthy: In 1996, Oron Catts and Zurr founded TC&A and began to develop a practice using tissue engineering that rapidly took shape following a residency at Harvard University (2000-2001). Based on TC&A's research model, Catts also co-founded SymbioticA (2000) - an artistic research laboratory within the School of Anatomy and Human Biology at University of Western Australia (Zurr, 2008: 24). Simultaneously, Adam Zarestsky (1998) joined up with Davis at MIT to develop works using bacteria (Nadis, 2000: 670). Kac approached bio art by collaborating with scientists to produce several genetic and transgenic artworks (Kac, 1999; Kac, 2000a; Kac, 2001; Kac, 2006b; Kac, 2009b).

Coming into the 2000s, there was an expansion and proliferation of interests amongst artists from various adjoining subject areas. Accounting for the breadth of artworks emerging in this period up until now (2012) is beyond the scope of this thesis, however a few general areas should be mentioned. Marta de Menezes used micromanipulation techniques to create patterns on butterfly wings (Menezes, 2000). Natalie Jeremijenko and Eugene Thacker explored bioinformatics, 'personalised lab' and aspects of DIY genetics (Thacker et al., 2004).

Several artists have used recombinant bacteria to produce visual art including Davis (Davis, 1986), David Kremers (Kremers, 1992), Kac (Kac, 1999), Al Wunderlich (Wunderlich and Davis, 2001), Marc Quinn (Quinn, 2001a; Quinn, 2001b) and the activist art group Critical Arts Ensemble (CAE) with Beatriz da Costa (Critical Art Ensemble and Costa, 2001). Working with genetically altered plants, Kac has also exhibited GM petunias in *The Natural History of Enigma* (Kac, 2009b) developed by scientists, others have incorporated consumer-available plants in their works, such as the arts collective BLC's DIY tissue regeneration of the GM blue carnations

[18] 'Iris Project' exhibited in 1988 at New Langton Arts (San Francisco).

'Moondust'[19] in *Common Flowers – Flower Commons* (Fukuhara and Tremmel, 2009) and artists duo Heather Ackroyd and Dan Harvey have used a GM-free strain of 'Staygreen' grass version (Gebbett, 2010) as a photographic media in several of their works including *Mother and Child* (Ackroyd and Harvey, 2000). The most iconic of genetic artworks to date has been Kac's *GFP Bunny* (Kac, 2000a)[20] named 'Alba' paving the way for art involving genetically modified animals (Illustration 2). Whilst *GFP Bunny* remains highly speculative (Davis et al., 2001: 2; Anker and Nelkin, 2004: 95) as an artwork both from a production and presentation perspective[21], Kac later developed the artwork *The Eighth Day* (Kac, 2001) featuring a terrarium of living transgenic organisms (including transgenic mice, bacteria, fish and plants) provided by scientists (Zaretsky, 2005; Cinti, 2011c: 149). However, in spite of the variety of artworks with living materials spanning across kingdoms, with exception of a few (e.g. Davis and CAE) most of these artworks lend themselves to traditional art practices rather than artists adopting scientific methods. Such focus, elaborated in section 3.1, on representation alone tends to circumnavigate biological meaning and only provide a limited if not anthropomorphic account of biological media. As will be discussed in Chapter 4, this research attempts to both shift artists' dependency on scientists by establishing a lengthily immersive practice in order to operate across these domains and provide a layered engagement with the media that closely integrates scientific methods with intuitive artistic approaches.

Bio art has also been approached by a surge of performance artists, of note are the body art pioneers Stelarc (Illustration 4) and Orlan, and artists Jennifer Willet, Zaretsky and Kira O'Reilly, using their own body as a site to explore bio media and ownership. It has been argued that performance and body art is closely connected to bio art through their 'shared dialectic' in terms of the structural relationship that connect the fields, that is, the ephemeral nature of the artworks and methods of preservation (Hauser, 2005: 184; Hauser, 2006: 132). Yet, the human body complicates the biological component if we are to follow Gessert's description of bio art as 'art made of or by living organisms' by collapsing all human art practices into the field. Capucci specifically excludes the human element from bio art (Figure 3) by characterising it as 'any art that is alive or contains living components that are not human' (Hauser et al., 2007). For Zurr, this provokes an 'exclu[sion of] artists working with the human body or artists working with human tissue and cells' (Zurr, 2008: 20). In addition to highlighting the problem of bio art's

[19] The first available floricultural crop (Tanaka et al., 2009: 5357).

[20] For instance, the work featured in a slide of the Nobel lecture for the 2008 Nobel prizewinner in Chemistry Martin Chalfie (Chalfie, 2009).

[21] 'Alba' was never actually exhibited and the photo shows a digitally manipulated green rabbit (Andrews, 2000: 22-24; Da Costa and Philip, 2008). See also Illustration 2.

subject boundary in relation to the human body, as we shall see in section 3.2, this also complicates the ethics surrounding the field.

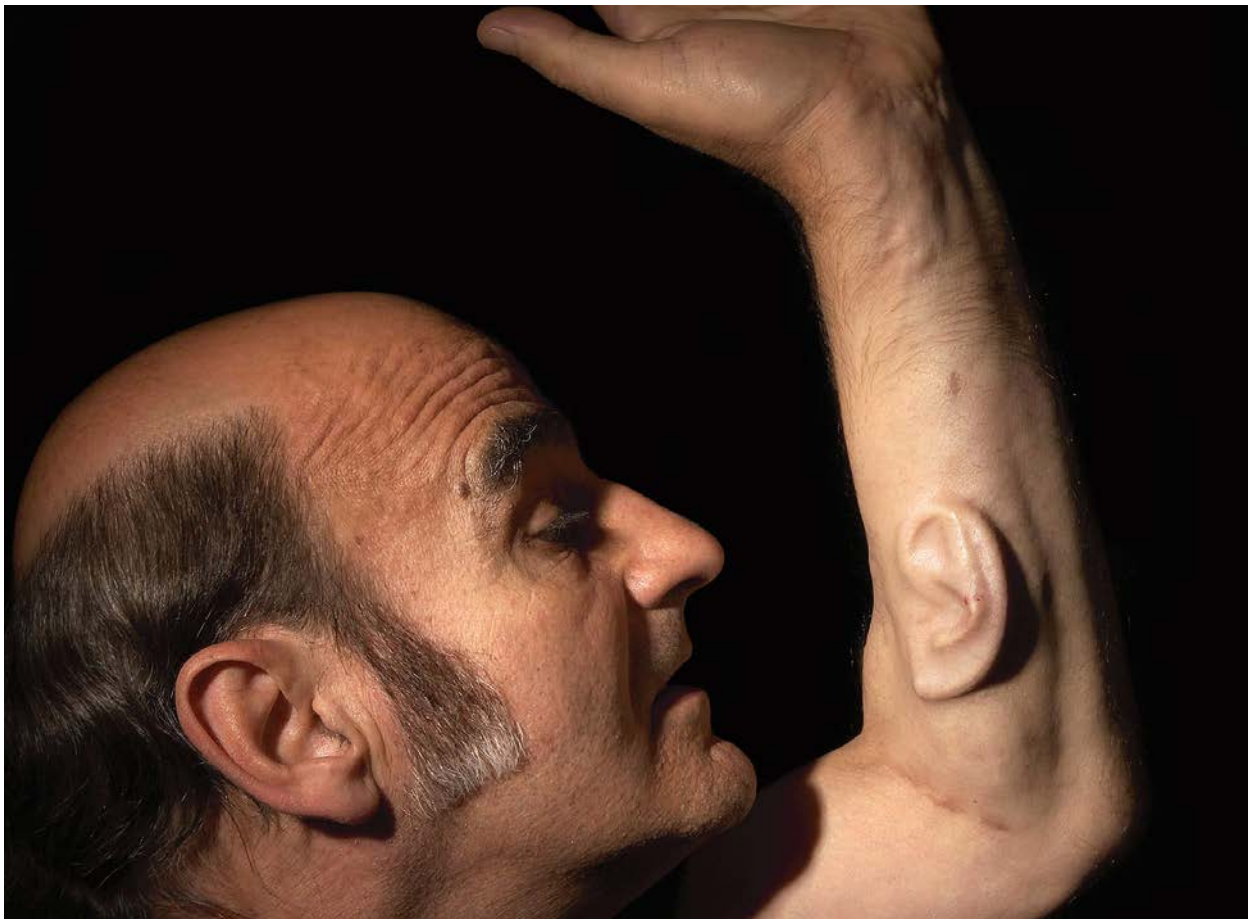

Illustration 4: Stelarc's *Ear on Arm* (Stelarc, 2010). Photo: Nina Sellars. Permission to reproduce this image has been kindly granted by Sellars.

A number of speculative bio artworks exist blurring the distinction between authenticity and fiction (e.g. of earlier works [circa 2000] include Kac's *GFP Bunny*, Laura Cinti's *The Cactus Project*, and Willet and Shawn Bailey's *Bioteknica*[22]), this has also prompted the need for many artists to stage an authenticity (or actively evidence processes and materials) as will be discussed in section 3.1 as well as ontological implications addressed in Chapter 4.

The increasing number of artists drawn to bio art and the problem of laboratory access has led to the escalation of DIY bio art practices (e.g. Andy Gracie, CAE, Willet, Marc R. Dusseiller, Anthony Hall), and further, the subversion of scientific tools (e.g. Vanouse, Davis, Gracie) to produce alternative representations (Illustration 1). These artists also reflect a need to build tools

[22] *Bioteknica* was the name of their former arts collective but was presented as a fictive biotech company and has therefore been understood as an art project in itself.

that adhere to a different type of aesthetic or representation than those born out of the biosciences.

Much use of biological material (e.g. bacteria and viruses) remains under legislation, particularly in a post-9/11 society, where the question of terrorism and government authority has changed. The most well known case involved the prosecution and later acquittal of the US-based artist Steve Kurtz, member of CAE, under otherwise tragic circumstances.[23] The case illustrates the challenges involved in developing research using biological materials and tools outside the confines of laboratory spaces in current political climates (Gere, 2005: 65-68; Lynch, 2007: 196-200). In addition, there are also health and safety considerations (i.e. accidental release of modified organisms) to be accounted for as these pose potential risks to health and environment. Publicly exhibiting GMOs was a challenge for this research and was resolved by developing a UK-specific framework (Section 6.3).

Currently, bio art remains dependent on institutions for access to facilities, expertise (i.e. universities) and funding (e.g. Wellcome Trust). Whilst the agreement around its subject boundary remains tenuous, what is becoming clear is that the field is a constantly moving territory alongside emerging technologies, such as synthetic biology. One problem thrown up by such novelty factors is that many previous and representational artworks become mapped onto these technologies due to the lack of actual works in emerging areas[24]. Artists and designers approach these new technologies through workshops or collaborations[25]. A current model for emerging graduate works[26] involves speculative approaches or speculative bio design suggesting future scenarios through traditional methods of representation (such as animation, video and prototypic objects). Such speculative strategies often tend to be conceptual as opposed to the material approach offered in this research, and as will be discussed through research outcomes (Chapter 5) required adoptions of specific contemporary scientific methods (i.e. synthetic biology) to actualise rather than speculate.

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[23] The case emerged after authorities discovered Kurtz having basic laboratory set-up and exchanging bio matter for his research. In May 2009, his wife went into cardiac arrest, after making an emergency call, the medical team unable to resuscitate Kurtz's wife also noticed what they believed to be suspicious material and decided to notify criminal authorities. FBI officers and personnel dressed in hazmat suits entered Kurtz flat, apprehending him and confiscating the material under suspicion of bioterrorism. The suspected material was later found to be part of Kurtz artistic research used in public interventions and debates surrounding GMOs.

[24] For example, 'Synth-ethic: Art and Synthetic Biology Exhibition' (Hauser, 2011).

[25] Including Catts and RCA graduates Alexandra Daisy Ginsberg, Sascha Pohflepp and Tuur van Balen.

[26] Royal College of Art (RCA) graduate exhibitions such as 'WHAT IF…' (Dunne, 2010b), 'IMPACT!' (Dunne, 2010a) and 'MA Design Interactions Show' (Dunne, 2009).

While many bio artworks use naturally occurring (non-modified) organisms (e.g. fungi, bacteria, or plants) or phenomena (e.g. bioluminescence), few artists engage with manipulation of bio matter in formal scientific contexts. Further, in terms of authenticity, much of the works developed by artists lack the use of evidence processes (e.g. protocols and documentary evidence) to produce more complex works in a scientific domain. Such approaches are needed to access and develop practices in emergent technologies beyond DIY, collaborative, conceptual and readymade (appropriation) capacities.

Bio art in its brief and sporadic history has seen multiple modes of expression but continues to focus on speculative approaches revealing that the manipulation and production of new life forms on discreet levels is not within the range of most artists approaching the field outside collaboration with scientists – in spite of its definitions hinging on these ideas. This suggests a need and opportunity (at least outside collaboration) for artists to explore bio art potentials through deeper assimilation of scientific aspects into their art practice.

## 2.5 Where to find bio art? The literature search

### 2.5.1 Literature on bio art

The literature on bio art tends to be secondary in the form of edited books (anthologies) and there is a great deal of 'grey' literature including theses, conference proceedings, exhibition catalogues and Internet essays. The overall status of our digital culture (circa 2012) means that much recent material has been digitised and made available through the Internet. Books reviewing technology, media, art and science, such as 'Art + Science now' (Wilson, 2010) cover broader art and science engagements. The grey literature is organised from a variety of sources such as exhibition catalogues[27], Internet essays from artists' websites, scholarly journals (e.g. 'Leonardo'), science journals (e.g. 'Nature' and 'Science'), conference proceedings[28] and online databases[29]. A loose body of writing is located in popular culture that include science magazines[30], sensational magazines, online newspapers[31], radio[32], television interviews[33], popular

[27] Examples include 'L'Art Biotech' and 'Ars Electronica'.
[28] Such as 'Aesthetics of care' and 'Mutamorphosis: Challenging the Arts and Sciences'.
[29] Including 'Rhizome', 'Leonardo-Online', 'Project Muse' and 'PubMed'.
[30] Such as 'The New Scientist' and 'Wired'.
[31] For instance, 'BBC online' and 'the Scotsman'.
[32] These include 'the bio blurb show', 'Resonance FM' and 'BBC Radio 4' science programme, 'Material world'.
[33] 'ABC-News'.

fiction (e.g. Michael Crichton's 'Next') and related movies[34]. Social media has provided another dimension to the literature such as 'Facebook', Mailing Lists (e.g. 'Yasmin' and 'Empyre'), LinkedIn (e.g. 'Bio-art group'), and blogs (e.g. 'We-Make-Money-Not-Art'). In addition, there is also an increasing dissemination of bio art documentation and artworks made available on video-sharing sites[35] or archived in websites[36].

### 2.5.2 The literature quality

The quality of the literature ranges from well-referenced and excellent peer-reviewed writings in databases like 'Project Muse' and 'Leonardo On-Line', to more informal sources such as artists' blogs and social media. Informal sources provide limited information but point to other resources and often give an indication of how artworks are received. There tends to be overlapping published or unpublished writings giving the impression of a more extensive literature. Overlaps range from complete articles or essays often included in both edited books and online essays to shorter formulations and arguments presented by the same authors across publications[37].

A common problem with social media, online blogs and popular magazines are their transient nature and qualitative issues such as insufficient referencing, chatty-nature (informal) and repetitive content. A few peer-reviewed periodicals provide concise insights to the field. For instance, the scholarly journal 'Leonardo' (MIT Press) is dedicated to disseminating information about projects that cross-fertilise art, science and technology. The scientific journals, 'Nature' and 'Science', provide excellent but infrequent articles or reviews on bio art. The 'Leonardo/ The International Society for the Arts, Sciences and Technology (ISAST)' website hosts a database, 'Leonardo ABstract Services' (LABS), covering MFA, Master and Ph.D. theses' abstracts situated broadly in the intersections of art, science and technology, and include discussions on the subject[38]. Databases, such as 'Rhizome', often have short postings of events, blogs, and interviews with artists and description of artworks. In addition, the scientific database 'PubMed' is a substantial information resource for locating articles such as those featured in 'Nature' and 'Science', but also in searching scientific and technical aspects for bio art projects. Central repositories to identify and access electronically published peer-reviewed art-science

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[34] 'Strange Culture', 'Heaven + Earth + Joe Davis' and 'BioArt - Art from the laboratory'.
[35] For example, 'YouTube', 'Blip.tv', 'Flickr' and 'Vimeo'.
[36] 'VIDA, Art and Artificial Life International Awards', 'Bio:Fiction Film Festival' and 'Ars Electronica'.
[37] For example, Kac's *GFP Bunny* (Kac; Dobrila and Kostic, 2000: 101-138; Kac, 2000b; Bulatov, 2004; Kac, 2005: 264-285).
[38] Such as Zurr, Cinti, Paul Thomas, Rob Le Frenais and Andre Brodyk.

journals include 'Project MUSE' and 'JSTOR' databases. Amongst edited books on the subject, there are a series of anthologies that show the development of the field through loosely interrelated discourses.

Kac and Gessert are bio artists who have both edited and written important anthologies[39]. Other anthologies of note include; 'Biomediale' edited by Dmitry Bulatov (Bulatov, 2004); 'Art et Biotechnologies' edited by Louise Poissant and Ernestine Daubner (Daubner and Poissant, 2005); and 'Tactical Biopolitics' by Beatriz da Costa and Kavita Philip (Da Costa and Philip, 2008).

Books covering the broader area of art and science such as Ede's 'Art and Science' provide useful discussions on the relationship between these fields, further Suzanne Anker and Dorothy Nelkin have outlined traditional representational relationships between artefacts produced in the fine arts and sciences. CAE offers a political perspective surrounding bio art activism in 'The Molecular Invasion' (Kurtz, 2002). A socio-technological perspective of bio art can be found in Thacker's books 'Biomedia' (Thacker, 2004) and 'The Global Genome' (Thacker, 2005), and provided useful concepts to discuss and situate this research's proposition (Section 3.1). Philosophical and critical discussions that unpick problems concerning the subject include publications, conference proceedings and books by: Hauser; Paul Virilio; Nicole Karafyllis; Kathrine N. Hayles; Kay Ellen Keller; Donna Haraway; Ingeborg Reichle; Thacker; Gunalan Nadarajan; Lori B. Andrews; and Vilhelm Flusser.

Literature from the aforementioned peer-review journals, edited books and databases were used for this research. Anthologies concerning bio art include specific writings by artists and theorists, and offer an introduction to the field. Articles, catalogues and conference proceedings provide key definitions and topical writings. Popular magazines, databases and artists' blogs were used to locate interview material on specific artworks or artists' background. Exhibition catalogues provide description of artworks, inform how the subject is situated with adjoining fields and help locate relationships between time periods and themes. Whilst there are no subject specific annual or bi-annual reviews on bio art, key conferences have been central to the formulation of the field. Some specialised bodies concerning bio art are useful, such as the Inter-Society for the Electronic Arts (ISEA) and Ars Electronica, hosting a database of archived conference proceedings and exhibition catalogues that feature artworks of bio artists (e.g. Hybrid Arts).

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[39] For instance, 'Signs of Life' (Kac, 2007) and 'Green Light' (Gessert, 2010).

Although scoping the field as a theoretical framework requires navigating a loosely coupled literature, the more immediate challenge facing practitioners is access to research laboratories (also noted in Section 2.4). How this was done specifically in this research will be discussed in section 4.5 by looking at how institutional arrangements were made and how materials were obtained from external institutions in specific works (Chapter 5). The availability and requirements for transforming bio matter has made bio art increasingly associated and dependent on academic institutions and organisations. As such, these bodies play a significant role in shaping the field by providing artistic and theoretical outputs.

### 2.5.3 Research institutions and organisations

Currently, a few research centres with specific focus on the subject exists. 'SymbioticA' is the most permanent art laboratory facility that enables artists to engage in 'wet' biology[40]. Successful applicants receive laboratory training specific to the art project they plan to develop[41]. The centre also runs undergraduate units, a postgraduate Master program and is currently (2011) offering Ph.D. opportunities. In Europe, there are several centres that provide either residency or are actively engaging in the subject. 'The Arts & Genomics Centre' (TAGC) based at the Faculty of Science, University of Leiden, offers research, educational programs and artist residencies[42]. Also in the Netherlands, the 'Waag Society' operates as an institute for art, science and technology with an event program[43]. In Portugal, 'Ectopia', an experimental laboratory affiliated with the Instituto Gulbenkian de Ciência, offers residency access to research facilities (e.g. de Menezes). There are also organisations working in the field as cultural producers, such as 'The Arts Catalyst' (UK) funded by the Arts Council of England, that organise workshops[44], exhibitions, funding and collaborations[45], alongside smaller and midsize organisations engaged in the field[46].

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[40] 'Wet' biology is a common term to describe biological practices that involve '*in vivo*' (e.g. taking sample from an organism) or '*in vitro*' (e.g. working with a sample from an organisms such as DNA) laboratory practices.

[41] The centre has hosted over 60 international residencies and is jointly funded by 'University of Western Australia' and the Western Australian Government's 'Department of Culture and the Arts'. Artists have included: Catts, Zurr, Zaretsky, de Menezes, Willet, Bailey, O'Reilly, Vanouse, Art Orienté Objet, Ginsberg, Kurtz, Orlan and Stelarc.

[42] For example, Willet, O'Reilly, Zaretsky and de Menezes.

[43] Includes electronics, bio art and wet lab workshops, performances, competitions and residencies.

[44] For instance, 'SymbioticA - BioArt Workshop' and 'Synthesis: synthetic biology in art & society'.

[45] Such as Kurtz, Catts, CAE, Zaretsky and Gracie.

[46] Including The Finnish Bioart Society, Trondheim Electronic Centre (Norway), International Centre for Art and New Technologies (CIANT) (Czech Republic), The University of Athens (Department of Communication and Media Studies), Swiss artists-in-labs program (Zürich), University of California (UCLA) Art|Sci Center (Los Angeles), the 'Foundation for Art and Creative Technology' - FACT (Liverpool); and Central Saint Martins' Artakt (London).

Relevant to this research and practice, is the internationally recognised organisation and arts collective C-LAB, co-founded by Cinti and myself in 2003 to publicly disseminate and provide resources (i.e. a comprehensive visual art-science database) specific to bio art through an online website. During the course of both Cinti's and my own research, C-LAB has served as a platform to circulate activities, engagements and works. As we shall see (Chapter 4), this has also resulted in a shared discourse stretching from Cinti's thesis and into this, in terms of how artists work with bio matter, scientific methods and biological meaning-making processes (briefly discussed in Section 2.4). C-LAB engages in a range of activities (e.g. exhibitions, talks, collaborations and curatorial) including establishing the European Public Art Centre (EPAC) in 2010-2012, and continues to provide written and visual dissemination of conferences adding a public and mobile record to events as a 'live happening'.

### 2.5.4 Exhibitions, conferences & competitions

Whilst research institutes and organisations have specific focus on the subject, exhibitions including bio artworks are often housed as part of electronic and media arts festivals. 'Ars Electronica – Festival for Art, Technology and Society' is significant in combining a cluster of high quality artworks with theoretical insights by scholars. Already mentioned in section 2.3 was the 1993 exhibition 'Genetic Art – Artificial Life' that offered initial discussions on the theme of bio art and also highlighted the fluidity surrounding the term 'genetic art' (Section 2.4). Focusing on modern biotechnology, the 'LifeScience' exhibition in 1999 was instrumental in bringing together several bio artists and theorists[47] providing the subject with some recognition as a field. Also the 2000 festival, 'Next Sex, Sex in the Age of its Procreative Superfluousness', continued its agenda on biotechnology[48]. 'HYBRID - Living in a Paradox' in 2005 included the paper 'Bio Art - Taxonomy of an Etymological Monster' by Hauser unpicking issues of materiality and representation in bio art, a subject of discussion in section 3.1.2. In addition to these exhibitions and conferences, the other division of Ars Electronica is the 'Prix Ars Electronica', described as:

> '[A]n interdisciplinary platform for everyone who uses the computer as a universal medium for implementing and designing their creative projects at the interface of art, technology and society.' (Stocker and Schöpf, 2011)

Since 2007 the competition has included the 'Hybrid Art' category dedicated to 'hybrid and transdisciplinary projects and approaches to media art' (Ars Electronica, 2007-) to accommodate

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[47] For example, Gessert, Kac, Andrews, Virilio, Bruno Latour, Manuel DeLanda, Flusser and Nelkin.
[48] Featuring artworks of Davis, Catts, Zurr and de Menezes.

for emergent media artworks[49]. A similar competition 'VIDA, Art and Artificial International Awards' organised by Fundación Telefónica offers prize money to its winners for video submissions[50]. Recently, the 'Designers and Artists for Genomic Award' (DA4GA) organised by a consortium of Dutch institutions[51] became open to international participants to compete for prize money to collaborate and develop artworks with Dutch institutions. Cinti and myself obtained the 2012-2013 award (Stalenhoef, 2013) to realise the artwork *Living Mirror* that began its development in this research (Section 5.11).

The first major exhibition to examine 'the meaning and urgent implications of dramatic breakthroughs in genetic research' was 'Paradise Now: Picturing the Genetic Revolution' in 2000 at 'Exit Art' in New York (West, 2003). However, it has been pointed out that much of the featured works related only thematically to biotechnology due to their use of traditional media such as paintings (Bureaud, 2002: 1). The 2002 travelling exhibition 'Gene(sis)'[52] organised by the 'Henry Gallery', also included thematic pieces by artists but only a few artworks dealt directly with bio matter[53] (Held, 2002). Characterised as a defining moment in the field, 'L'Art Biotech' in Nantes (France) at 'Le lieu Unique', curated by Hauser in 2003, exclusively featured works that materially engaged with biotechnology, highlighting bio art's separation from artworks using traditional representation. A widely recognised electronic arts event in the Asia-Pacific region that frequently includes works by artists developed during SymbioticA residencies[54] is the 'Biennale of Electronic Arts in Perth' (BEAP). I have also had the opportunity to partake and exhibit in the first museum-based exhibition 'Bios4, Arte Biotecnológico y Ambiental' curated by Antonio Pinto in 2007 showing works involving both artificial and biological life over an extensive period at Centro Andaluz de Arte Contemporáneo, Seville (Spain) (Debatty, 2007). Another useful insight was offered by participating in the 'Enter 3, the Third International Festival for Arts, Sciences and Technologies' in Czech Republic[55], including a conference and

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[49] Notable winners of its first prize, the 'Golden Nica', have included SymbioticA (2007), Kac (2009), Stelarc (2010), Art Orienté Objet (2011) and Davis (2012) (Catts O. and Zurr, 2007b; Kac, 2009c; Stelarc, 2010). 'Award of distinction' has included van Balen (2011) and Vanouse (2010).

[50] Focusing on technological innovations related to the arts with winners from bio art including SymbioticA researchers (Guy Ben-Ary, Philip Gamblen, Peter Gee, Nathan Scott, Brett Murray and Dr. Steve Potter [and his group])(2006) Catts and Zurr (Catts O. and Zurr, 2007a) and Vanouse (2002). Special mentions were given to artists and designers Ginsberg and Pohflepp (2009) and Gracie (2006).

[51] The Netherlands Genomics Initiative, the Centre for Society and Genomics, Naturalis Biodiversity Centre, and Waag Society.

[52] A title taken from Kac's work 'Genesis' (Anker and Nelkin, 2004: 95).

[53] For example, Kac, Vanouse, Christine Borland and CAE.

[54] Such as Biofeel (2002) and BioDifference (2004).

[55] Coinciding with the 40th anniversary of 'Leonardo Journal' and 'Mutamorphosis: Challenging Arts and Sciences' conference.

multiple exhibitions showing mostly video documentation of biological works. 'Sk-interfaces' (2008) exhibition held at 'FACT' in Liverpool (UK) and curated by Hauser was the 'first exhibition of its kind in the UK' (FACT, 2008)[56]. In addition, 'Design and the Elastic Mind' exhibition at MoMA (2008), generated a lot of publicity[57], particularly when the curator was asked by the artists to switch off the bioreactor subsequently 'killing' the living exhibit, 'Victimless Leather Jacket', Illustration 5 (Catts and Zurr, 2004a). The show focused on how designers deal with scientific and technological developments[58]. The exhibition 'Visceral: The Living Art Experiment' (2011) was dedicated specifically to SymbioticA's 10 year anniversary, curated by Catts and Zurr and held at the 'Science Gallery' in Dublin (Ireland). A central question in the exhibition was why this technology (referring to biotechnology in general but tissue engineering specifically) makes us feel uneasy as opposed to digital technology.

A 'handful' of exhibitions[59] have been dedicated to bio art (Hauser, 2005: 182) featuring few but reoccurring artworks shown in relation to varying themes[60]. Living bio artworks have been exhibited in conjunction with new media and electronic works[61]. In addition, documentation of bio artworks and rudimentary artefacts are frequently presented in bio art exhibitions rather than their living counterpart[62]. Like electronic art, bio art adds new pressure to exhibition venues such as the need to provide special (often sensitive) environmental conditions for living artworks. For instance, prior to 'Steichen's Delphiniums' exhibition, Illustration 3, he placed a newspaper posting warning that severe weather may hamper the blooming of the flowers (The Museum of Modern Art, 1936)[63]. Gessert elaborated on this issue as his irises bloomed out days before his exhibition opened, leaving the space filled with pots showing only stalks, highlighting the precariousness of exhibiting living matter. Further, he noted that whilst museums generally produce 'neutral' (i.e. white) background for art objects, surrounding gardens remain elaborate and ornamental (Gessert, 1993: 209). Using the traditional white cube metaphor he proposed a similar arrangement for museum gardens. However, if bio art is to take part in the post-

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[56] Including a feature on BBC News.

[57] Such as TED and news cables worldwide, from CNN to BBC.

[58] Included works from (sixteen) RCA staff, graduates and students (RCA, 2008).

[59] 'L'Bio Art', 'Visceral' and 'Bios 4'.

[60] For example, 'Worry Dolls' (Catts et al., 2000) is shown in relation to multiple technologies and themes.

[61] For instance, 'Hong Kong New Media Festival', 'Transmediale', and 'Ars Electronica'.

[62] Such as 'Enter Festival', 'Today in Paradise – Genetics and Art' in Sweden and 'Dias Bioart' in Spain.

[63] 'Because of the recent cold, rainy weather, the dates given below may have to be postponed a day or two so that the delphiniums may be in full bloom. Please mention this weather-permitting clause and suggest that all interested persons consult their newspapers Wednesday for any postponement of the opening. This release is for publication Monday, June 22. If the opening date should need postponing, all newspapers* will receive word to that effect Tuesday afternoon, June 23.' (The Museum of Modern Art, 1936).

biological phenomena and introduce itself as taking account of new artistic conditions, why is it still lingering in traditional ways of presenting itself? One question is whether bio art should be exhibited in gallery conditions at all, as perhaps more relevant places to view such artworks could be in laboratory spaces, out-door spaces (discursions) or alternative hosting conditions[64]. One answer is the difficulty for audience to access laboratory spaces (being both restrictive and working environments), and as bio artists explore increasingly regulated areas of biotechnology specific permissions and protocols will be required for such works to be shown in public settings (Section 6.3). For living works, a new requirement during exhibitions is feeding. For instance, the 'Bios 4' exhibition lasted over three months and curators (and museum staff) had to assume the role as feeders and carers. How well this aspect is understood by curators and organisers, and to what extent the audiences taking part in such processes, hint to why bio art is proposing its artworks as living subjects rather than traditional art objects. Zaretsky's 'Workhorse Zoo' (Zaretsky and Reodica, 2002), a performative installation with laboratory animals, included bringing the audience into the processes of feeding, caring and killing. As mentioned, Catt's and Zurr's semi-living sculptures use the notion of a 'killing ritual' whereby audience were invited to switch off the bioreactor (Schwartz, 2008) (Illustration 5) or expose tissues to an open environment (i.e. non-sterile conditions).

> As genetic artists depart from symbolic representations and veer into the unprecedented domain of manipulating life and its codes of operation, they are contending with unfamiliar technical and biosafety requirements, architectural restraints and special climatic conditions for display in museums or galleries. These are often ill-equipped, unable or unwilling to face the challenges that the showcasing and handling of such art requires, whether for legal and security issues or for fear of public perceptions and misconceptions about potential biohazards. However, some museums and galleries and a growing number of artists have begun to address and amend these problems. (Catts et al., 2000; Catts and Zurr, 2000-2001; Catts and Zurr, 2004a)

Given the difficulty of maintaining living works and the ethical questions raised, museums are not common places to experience bio art. Festivals, galleries and smaller events are better suited for dealing with the technical challenges and place less pressure on maintaining living works due to short exhibition periods.

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[64] Existing examples include 'Love Motel for Insects' (Ballengée, 2001- ) and 'BioARTCAMP' (Willet, 2011).

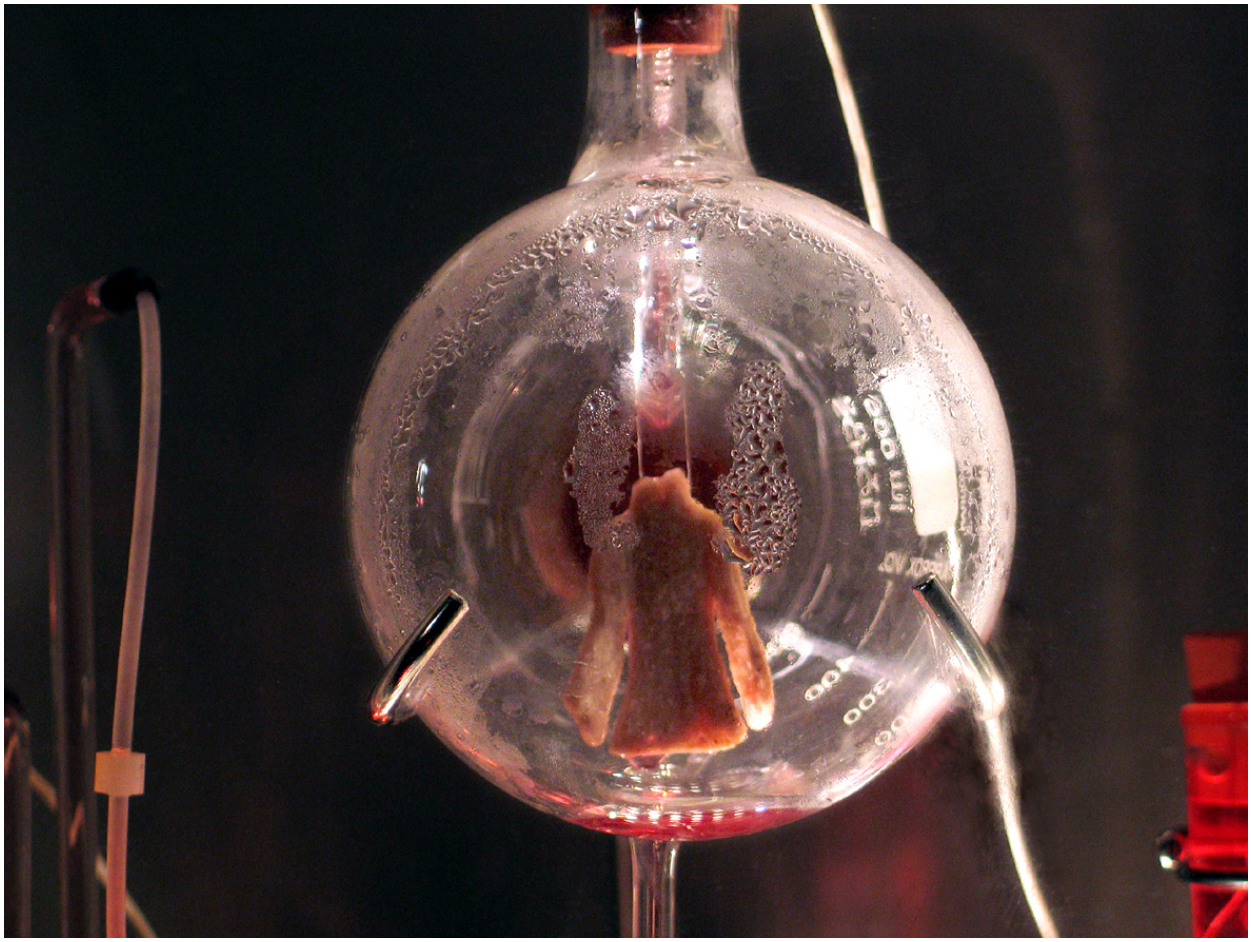

Illustration 5: TC&A, *Victimless Leather: A prototype of stitch-less jacket grown over techno-scientific body*, 2004. (Catts and Zurr, 2004a). Permission to reproduce this image has been kindly granted by Catts and Zurr.

While many exhibitions have included symposia, of specific relevance was 'The Aesthetics of Care' (2002) that dealt with ethical issues and positions of artists working with living material through technology. Networks of importance for the current state of the field include 'Synthetic Aesthetics' that attempts to develop international collaboration and exchange between designers, artists and scientists around the theme of synthetic biology. 'Yasmin' has held many online debates that have shaped the field of bio art both directly and indirectly in terms of subject boundary, definitions and practices (Section 2.3).

The scope of bio art has mutated over time as a consequence of technological emergence and the proliferation of exhibitions, conferences and literature, which underlines how much attitudes towards the field have changed in such a short time.

## 2.6 Summary

With few artworks, many discourses and a brief history, bio art remains a tentative but emerging field. Certain characteristics are valuable to note as they help situate this research, such as the transformation of bio matter (often living) through methods adopted from the biosciences and the subsequent challenges of ethics, regulation and evaluation emerging in the wake of employing bio matter as art. Several approaches (e.g. DIY, performative, speculative and material) provide bio art with many entry points from adjoining fields and consequently have resulted in a plurality of terms (e.g. transgenic art) used to describe particular practices within bio art. While definitions of bio art often point to the transformation of bio matter on discreet levels (e.g. genes, proteins, etc.), they fail to address how artists engage with these scientific operations, which is an aspect integral to how bio art is employed in this research. In discussing the field as a whole, Gessert's suggestion of bio art being an umbrella term for existing biologically related art practices is useful and can be broadened to include art involving the biosciences. Given the historical shift from representations to material practices, the umbrella term may serve to include contributing works now seen as precursors to the field. As will be discussed in the following chapter, this research approaches bio art through the use of living material, methods and suggests alternatives and emerging understandings on how bio art can be employed. Indeed, the fragmented literature does little to clarify bio art practices and tends to focus on ethical perspectives. This research therefore aims to lay bare its processes such that it may provide relevant approaches, if not fixed answers.

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# Chapter 3
# Theoretical framework

## 3.1 Matter, mediation and presence in bio art

Around 2000 when a definition of bio art was emerging, a plurality of artistic expressions explored the post-biological phenomenon (Section 2.1) causing a rift between those approaching the subject using traditional media (e.g. painting) and those working directly with biological tools and materials (e.g. genetic and tissue engineering). The problem can be looked at by (1) accounting for reactions to the post-biological in terms of thematic representation (Section 3.1.1), (2) how the schism emerged from dealing with biological matter as a media (Section 3.1.2) and (3) finally how bio art does not entirely isolate itself from thematic representation, neither in terms of media nor approaches.

### 3.1.1 The post-biological, artistic reactions and thematic representation

The period leading up to the 2000s was dramatic as the biosciences got caught up in media frenzies such as 'the Vacanti Mouse' (Illustration 6), 'Dolly the Sheep' and 'HGP' (Gaskell and Bauer, 2001: 4). Scientific images and discoveries suggested an increased ability to radically alter nature and deeper connections between biological codes and expressions.

Artists became influenced by a whole system of signs (e.g. DNA, chromosomes, genes, etc.) and the opportunities to exert transformative power over life offered by the biosciences.

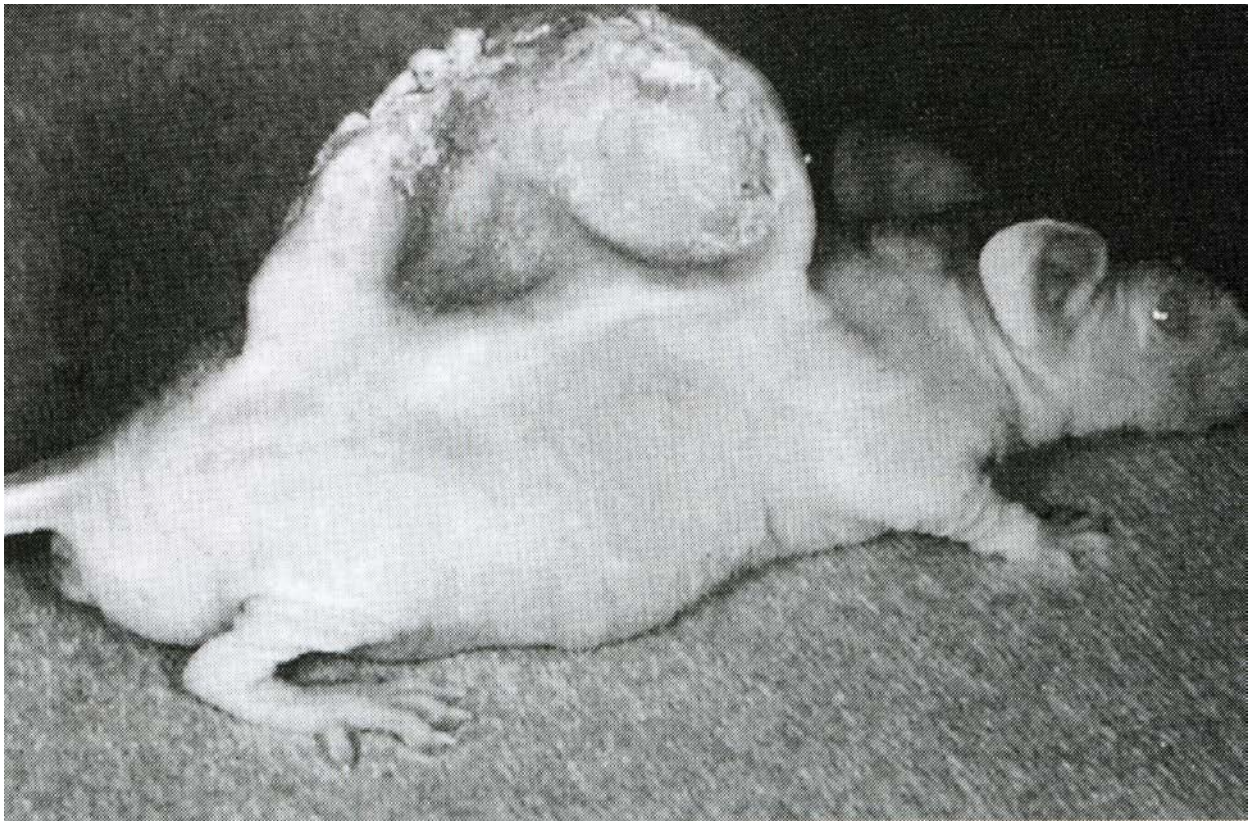

Illustration 6: Mouse growing tissue around scaffolded cartilage shaped into a human ear (Cao et al., 1997). Image credit: Cao, Yilin; Vacanti, Joseph; Paige, Keith; Upton, Joseph; Vacanti, Charles, 'Transplantation of Chondrocytes Utilizing a Polymer-Cell Construct to Produce Tissue-Engineered Cartilage in the Shape of a Human Ear', 'Plastic and Reconstructive Surgery', vol. 100, issue no. 2, page 305. Reproduced with permission of Wolters Kluwer Health.

The artistic response was broad and included those that expressed themselves using traditional media, such as painting (e.g. Alexis Rockman, *The Farm*, Illustration 7), sculpture (e.g. Thomas Grunfeld, *Misfit* and Paul McCarthy, *Tomato Heads*), print and photograph (e.g. Bradley Rubenstein, *Boy with puppy dog eyes*). Still others, used more recent computational arts, such as algorithms that employed genetic data (e.g. Ken Rinaldo, *Machinic Diatom*); yet others used eclectic mixes of media (e.g. Eva Sutton, *Hybrids*), whilst only a few sought to use biological media directly. For the purpose of this research and in what follows, I will use 'thematic representation' (or simply 'representations') to refer to the range of artworks and expressions exploring the post-biological using non-biological media. The question asked, was whether all these artworks could be classified as bio art or only those using biological media?

Illustration 7: Alexis Rockman, *The Farm*, 2000. (Rockman, 2000). Permission to reproduce this image has been kindly granted by Rockman.

### 3.1.2 Bio media

Discussions in the field have indicated a difference in artworks dealing with the post-biological (Section 2.1) that employ living media or bio matter as opposed to those employing traditional art material. Several scholars and artists working with manipulating biological media argued that the use of living matter constituted a departure that should be used to define bio art (e.g. Zurr, Hauser and Kac).

Artists interested in the processes of life are hardly a new phenomenon. For instance, much of the focus of art production in 1950s and 1960s was concerned with the 'blurring of art and life' (Kaprow and Kelley, 2003) and participatory art practices, first from 'Fluxus Art' (e.g. John Cage, Beuys and Allan Kaprow) and later with 'dematerialised art' (Lippard, 1973: 43) and 'conceptual art' where 'the idea becomes a machine that makes art' (Lewitt, 1967: 1).

Interactive and participatory practices were also models for computer-based or 'digital art', however the representational function of computer-based systems are less fixed than earlier representational forms (e.g. animated pictures or film sequences) (Heibach, 2000: 47-51) and include biological approaches using 'genetic algorithms' towards the production of 'artificial life'. Further, as pointed out by Capucci in section 2.3 and as proposed by theorist and artist Peter Weibel[65], biological approaches to the digital demonstrate that life is a consequence of a 'logical structure' that can be separated from its material basis (Gerbel and Weibel, 1993). Weibel suggests an extended idea of artificial life that includes technological intervention of bio matter (e.g. genetic engineering) but where life is more broadly understood as immaterial. The logic, consistent with Capucci's diagram (Figure 3), suggests a relationship between non-carbon (digital) and carbon-based (biological) life that renders biological life into a subset of immaterial understandings of life and subsequently places bio art a subset of computational art practices. However, according to Hauser, in light of programmatic strategies in 'wetworks' such as transgenic art and cloning (pointing to Kac and Jeremijenko), the use of the term 'genetic art' (referring to algorithmic computer-based art, Section 2.3) as 'a holdover from software times' is 'almost totally devoid of meaning' (Hauser, 2005: 184). In other words, given recent advances in the biosciences, where genetics is concretely explored by artists, it is today more appropriate to discuss 'genetic art' as an art involving bio matter rather than software algorithms.

Thus, in light of these movements three questions emerge. Firstly, and as already pointed out, why are the material practices of bio art seen as distinct from those using traditional types of media (e.g. paintings of modified bio matter such as Illustration 7)? Secondly, when broader debates around new media (e.g. Weibel and Cappucci) highlight a complex dependency between the digital and biological[66], why does bio art remain focused on material debates? Finally, what sort of experience is offered and what challenges invoked by staging biological matter (i.e. genetically modified organisms) as an actual presence (as opposed to pictorial representations)?

The attention paid to materiality in bio art suggests that mediation takes place through biological media. A key aspect is how these are reified as opposed to simulated, as is the case of new

[65] In the 2003 Ars Electronica exhibition 'Genetic Art – Artificial Life' discussed in section 2.5.4.

[66] In suggesting that digital artificial life has greater transformative potential and subsuming the biological as another logical structure (Section 2.3).

media[67]. However, this division may not be as clear-cut when considering that biological mediations are highly dependent on the digital domain (i.e. bioinformatics). Section 5.6 provides one example of how this practice employed digital tools (i.e. online databases and sequence analysis software) to evidence and allow biological construction and implementations of a genetic construct (more generally described in Chapter 4). More broadly, the integration of information technology (i.e. databases, modelling software, etc.) in modern biotechnology complicates the separation between the biological and digital – in the sense they both configure biological materiality[68]. Thacker, in his book 'biomedia', proposes the term 'bio media' (or 'biomedia') to encompass this 'dual investment in biological materiality, as well as the informatics capacity to enhance biological materiality' (Thacker, 2004: 6). Bio media is configured between the digital and the biological through a flow of information that become internalised in the biological and mediated as biological processes. This is different to hybrid configuration (e.g. a mechanical prosthesis) where the biological is partly replaced or extended by technology, rather as Thacker puts it, with bio media "'technology" appears to disappear altogether' (Thacker, 2004: 6). To discuss bio media as media itself is therefore to account for processes and functions of the biological and to inquire both technically and philosophically into the question of "what the body can do?" (Thacker, 2004: 6). This is critical to the understanding of how bio matter is dealt with in this research – that is, as a media involving techniques that enable a different order of extended capacities (i.e. novel expressions or properties) in the living to emerge. For instance, in the work *katE*, discussed in section 5.6, the capacity of bacteria was extended by developing a genetic system that allowed oxidative stress to be visualised through fluorescence (Illustration

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[67] New media as discussed here incorporates the ability for it to refashion old media through processes of what Grusin and Bolter calls the double logic of remediation (or repurposing), whereby media disappears leaving us only the thing presented (immediacy) through a process of mediation (e.g. real-time photo from a web-camera) and is multiplied (hypermediated) allowing multiple part of the media to be simultaneously controlled (e.g. as selecting a song from a jukebox while viewing photos from a web-camera) (Bolter and Grusin, 1999: 1-20). Together these processes aim to become more real than the real, in the sense that they evoke an immediate and authentic emotional response. Lev Manovich has suggested key principles inherent in new media (i.e. numerical presentation, modularity, automation, variability and transcoding) such as its capability to perpetually mutate itself once digitised through processes of transcoding (Manovich, 2001: 49-63). Thacker analyses the relationship between new media and bio media, wherein the latter is understood as a complex, situated in both the digital and material but always on the side of the material (Thacker, 2004: 10-11). From the perspective of bio art, at least in my opinion, the material aims of bio media can be distinguish from dematerialised aims of new media in spite of new media always being bound to physical hardware as noted by Hayles (Hayles, 2002: 6). However, in spite of these differences – what is interesting when comparing bio art to new media art, at least if we follow Simon Biggs' interpretation of new media art involving 'development and/or application of emergent mediating tools and systems', we find often shared methodological grounding in how artistic processes are employed to investigate novel hybrid spaces (Biggs, 2009: 1).

[68] This is also an important debate in the sciences' move towards 'systems biology' approaches. It suggests changing existing views of scientific method through a gradual shift away from laboratory-based experimentation to computation biology to solve complex biological questions. Ongoing automatisation and standardisation in synthetic biology partakes in this agenda by promising processes that can produce and implement genetic systems using fully automated digital and robotic systems (Section 4.14.3).

42). Notably, even for those artists adopting a material practice of bio art, the suspension between material and information captured in bio media is seldom employed or discussed, instead, the material distinction in bio art is argued more broadly through a presence of the living bio matter.

Whilst virtual representations are of metaphorical, conceptual and symbolic nature, bio art on the other hand presents the audience with the living, a presence that shifts both the artist and the audience positions in that the living matter is expressing an extended capacity (of a different order) staged by the artist. Presence is here understood as what is tangible to the human body (Gumbrecht, 2004: xiii) in the foremost sense of having impact on sensory, cognitive and affective processing system (Lombard and Ditton, 1997). While contemporary debate on the concept of presence is associated with a medium's ability to mediate a level of realness or fidelity that bring about an 'illusion of nonmediated' through remediation (i.e. particularly immediacy) (Lombard and Ditton, 1997), in bio art this concept is understood through inverse conditions as 'actual presence' where both the human audience and the bio matter is occupying the same space. Artists may seek to further breakdown boundaries (e.g. containment vessels hosting, protecting and feeding the living matter) that separate the human audience and the living 'other' in order to 'stage' a heightened fidelity of such presence (e.g. in the living installation of TC&A's *Pig Wings*, Illustration 8, where audience were invited to touch the tissues displayed).

Illustration 8: *Pig Wings* (Catts and Zurr, 2000-2001) coated in gold and displayed in Jewellery boxes. During the living installation of the works petri dishes were opened and audience could touch and contaminate the displays © 2011 Catts, Zurr and GV Art. Permission to reproduce this image has been kindly granted by Catts and Zurr.

Further, this suggests that aesthetics based on the 'production of presence' requires bio art to 'stage an authenticity' (Hauser, 2006: 131). To draw a contradistinction between thematic

representation and material presence of living matter involves discussions of complex ontological issues outside the scope of this thesis (i.e. theoretical foundations of Martin Heidegger, Edmund Husserl and Maurice Merleau-Ponty), however, if we take a 'standard approach' to mean a 'type of experience' (Floridi, 2005: 657), then in terms of bio art the produced presence would be an actual experience of the living as media rather than a representation. Although this does not completely address what is mediated by or through the living matter, it does suggest that bio matter in its presence is an aesthetic component of bio art. The difference in bio artists' response to the post-biological can therefore be described by what Hauser calls 'media adequacy':

> […] to address biotechnology related issue in their very presence rather than in their symbolic representation (Yasmin, 2005-: Message 1, 29th May 2011).

However, in spite of (Hauser) pointing to the definition of bio art as 'an art of transformation *in vivo* that manipulates "biological materials at 'discrete levels (i.e. individual cells, proteins, genes, nucleotides)"', this material position is discordant with Thacker's definition of bio media that aligns the digital and the biological as transformative systems (e.g. bioinformatics and genetics). Bio art understood through the concept of bio media (Thacker) threatens to exclude much of existing bio art that operate independently of informatics (e.g. artists working with tissue culture [Illustration 8]). Instead, Hauser's understanding of bio art suggests that artists are 'purporting' an interrelationship between (1) biotechnologies and (2) personal, philosophical, political and economical framings. Borrowing from literary theorist Hans Ulrich Gumbrecht, this two-fold status of bio art produces an ontological oscillation (Gumbrecht, 2004: 2,49)[69] between a 'real presence' and a 'metaphorical representation' comparable with performative art (Hauser, 2005: 185)[70]. While, this research concurs with the importance of actual presence of bio matter and that much of bio art has been driven by performative (and metaphorical) practices, it also points to a clear oversight these tendencies have in dealing with actual biological processes. Performative bio art has provided a rich set of debates using metaphors and staged the presence of the living in a symbolical manner to fuel important debates[71]. Effective as this might be, it also opens the field to questions of whether the living presence has any biological significance outside metaphorical readings with the resulting effect of actual presence being at a distance to itself and

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[69] It seems that Hauser is here playing on what Gumbrecht calls an oscillation between a 'presence effect' and a 'meaning effect' needed to build a relation to things in the world.

[70] While this seems counterintuitive given that media-adequacy is on the side of material presence rather than symbolic representation, media-adequacy as a division between materiality and representation does not carry any ontological statement about the material or its role (e.g. biological meaning or processes) but shifts this to the domain of symbolic representation (e.g. metaphor).

[71] For example, *Disembodied Cuisine* (Catts and Zurr, 2003a).

prompting the question: What is then the role of the living, if such preoccupation is dominated by metaphorical aspects?

Of course, it can be argued that organisms subjected to wider socio-economical forces are impacted by changing attitudes, but this is a very broad understanding of biological processes and does not sufficiently address the specific nature of how such forces become incorporated as biological processes. Thacker takes this notion further by claiming in the case of bio media that this 'infinitely defers any referent' of what we might 'contingently refer to as a body' and 'deny tropic materialisation' or 'the real effect of corporealisation' (Thacker, 2004: 11). Although many artists and theorists would argue that bio art practices involve an equal fit of metaphorical and cognitive approaches (that actively takes account of knowledge processes), the question here is the extent to which a cohesive evidence platform is maintained to support the cognitive aspect or if these processes are merely drawn from subjective artistic understandings (a common method in traditional art practice) that fails to take scientific processes seriously – in spite of employing the latter to imbue a cognitive status in the work. Indeed, it can be said that, if art is to stake claims in terms of research and be taken seriously as an inventive discipline, does not then authenticity become a valuable commodity? We will return to how this research sought to incorporate biological processes in Chapter 4 but it is worth noting that Cinti, in her doctoral thesis, provided several case studies that problematise this aspect of bio art (Cinti, 2011c). In agreement with Cinti, this research also argues that avoiding issues of biological signification bites at the core of the defining characteristics of bio art and its ethical stands.

On the other hand, Hauser claims that artists working with speculative and even hoax-like aspects of bio art are profiting from 'the impossibility of certifying biological processes as genuine' (Hauser, 2005: 185). The contradistinction in this statement is interesting as it suggests that existing bio artworks are indeed tapping into genuine biological processes but unable or unwilling to disclose such evidence. Certainly, it can be challenging for an audience to verify claims and artists may purposely choose to equivocate when it comes to methods and the nature of a work. While this adds another layer to bio art, it also has practical implications in terms of locating evidence of previous GMO exhibitions in the UK, it resulted in the development of a legitimate framework for publicly staging artworks developed in this research (Section 6.3). The need to 'stage an authenticity' in this context is indicative of bio art involving epistemological and ontological questions surrounding our ability to verify such outcomes, to which Bureaud argues:

> The only way of "verifying" what the artists say is to use the same scientific methods in identical laboratories, and with the same scientific knowledge. Since this is impossible, we have to "believe" that it is what they say it is —or in some cases, have our "doubts", given what we know to be "possible". Grasping these works takes knowledge, but then shouldn't a citizen be informed? (Bureaud, 2002: 46)[72]

For instance, Davis work *Microvenus*, introduced in section 2.4, where a message (a symbol) is inscribed into *E. coli* bacteria, has been described as conceptual:

> Since bacteria and DNA are invisible under ordinary circumstances, *Microvenus* functions largely as a conceptual work. However, DNA and [*E. coli*[73]] are much more than ideas, so *Microvenus* also highlights the power of invisible realms, and the faith that we invest in genetics. (Gessert, 1999: 8)

Davis recognises that 'many of the structures and substances associated' with modern biotechnology are for 'the most part' invisible but argues that '[*Microvenus*[74]] DNA and the invisible structures containing it, are very real' (Davis, 1995: 3). Whilst Davis is more comfortable in accepting this dilemma, TC&A's 'feeding' and 'killing rituals' (i.e. where audience touch and contaminate living tissue cultures) provides a concrete example of 'staging an authenticity' by highlighting the aliveness of their tissue sculptures to suspicious audiences (Illustration 8).

Artists have on several occasions exhibited bio matter that are rudimentary artefacts[75] from experiments or bio matter either previously shown or developed (e.g. Gessert, 1994-; Catts and Zurr, 2003/2005; Kac, 2006a; Willet and Knight, 2006; Da Costa, 2006-2008; Stelarc, 2007; Boland and Cinti, 2007/2009). Bio art as living matter often ends up as inert or in the form of documentation due to the subsequent expiry date or cessation of life, and secondly by involving site-specific performances (e.g. live experiment or medical operation). How do we understand such material as bio art in the sense that they refer back to previous 'authentic presences'? Hauser and Gessert argue that such material produces a 'synecdoche' (Hauser, 2005: 185; Hauser, 2006: 132) in that it refers back to an operation where the living was once present, thereby validating artworks as bio art. This re-materialisation of documentation, as noted by Hauser, shows the 'shared dialectic' between bio art and performance art (Section 2.4). In addition to the issue of authenticity, documentation provides bio art with a much-needed mobility given financial, legal and material constraints of reproducing such works across

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[72] Informal discussions with Bureaud at Mutamorphosis 2012 conference in Prague suggested that such expectancy of audience informing themselves might have been a naïve assumption.

[73] Italics mine.

[74] Italics mine.

[75] Including videos of experiments, dried out tissue, plant stubs, photographs, etc.

countries and regulatory frameworks. For instance, in this research a UK framework was devised to legally show its GMO-based artworks, however, this does not readily apply in other countries and to prepare these works requires access to laboratory facilities near exhibition venues.

While the intangibility of bio matter poses epistemological challenges (e.g. working with transparent liquids or verifying biological expressions), the material characteristic remains a distinguishing feature in bio art. For instance, in selecting artists for his book 'Signs of life: bio art and beyond', Kac wrote:

> While the writers and artists herein explore the myriad thematic pathways of the biotech culture, all of the artists also engage with biotechnology on a material level. (Kac, 2007)

Zurr (Zurr, 2008: 19) and Gessert have produced similar arguments, the latter in attempting to draw subject boundaries for the field (Section 2.3). Hauser takes the thematic notion further by completely dismissing such representational works as bio art:

> Bio-fictional manifestations such as chimera-sculptures, DNA-portraits, chromosome-paintings or mutant-depicting digital photo-tricks are no more examples of Bio Art than Claude Monet's impressionistic paintings could be classified as "Water Lily Art" or "Cathedral Art". (Hauser, 2005: 182; see also Kac, 2007: 19)

The problem posed by this separation is that it excludes a large body of works examining the biological paradigm thematically. This can be thought of at least in two ways: firstly, a thematic approach can explore areas outside individual, institutional and societal boundaries, such as issues concerning extremely dangerous bio matter, ethical problems beyond the scope of material practices and attitudes relating to 'technological paradigm' (i.e. imposing material conditions uncritically); secondly, there will almost always be a link between thematic and material developments, and for many artists thematic exploration is a stepping-stone to explore bio matter itself. Hauser admits that bio art has been drifting from representational objects interested in the 'code of life' towards the current state of affairs which he sees as a set of 'transformational processes with performance characteristics [...]' (Hauser, 2005: 182).

Whilst further discussion of this topic is beyond the scope of the thesis, it may provide a more complete analysis of how the field has undergone a series of stages. Divergent accounts of art involving biotechnology show scholars on the one hand inclusive of wider thematic and cultural concerns (e.g. Nelkin, Anker and Ede) and the other solely focusing on artists using bio matter (e.g. Hauser and Kac).

The current interest in materiality in bio art involves a departure from immaterial concerns (e.g. thematic representation and genetic algorithms in digital media) towards a focus on living

material as a subject in its own right. This shift involves a mediation achieved through living biological expressions and processes. Thacker's proposed 'bio media' concept reminds us that while different from new media, the manipulation of bio matter (e.g. genetic engineering) is a configuration that takes place both in digital and biological domains. Characterising bio art as a material practice employing this configuration would exclude much of existing bio art practice (e.g. tissue culturing) in spite of being more aligned with modern biotechnology (e.g. modelling, bio informatics, etc.). Discussions have instead focused on how the actual presence of living matter adds a particular aesthetic characteristic to the field that further differentiates it from other approaches (i.e. thematic representation). Hauser has also attempted to use this aspect to frame bio art as having performance characteristics, while Kac has provided a more progressive account that clearly situates the field against existing traditions in contemporary and modern art movements. Much of existing bio art has involved performative aspects and it has been argued by Hauser that the status of bio artworks can be understood as an oscillating interrelationship between (1) actual presence of biotechnologies and (2) metaphorical representations based on personal framings.

This research suggests that in addition to bio art having metaphorical signification that fuel specific ethical, political and social debates, it is also capable of partaking in processes that deal with biological signification of the material itself. In this sense, this research is better aligned with Thacker's idea of bio media by investigating extended capacities in bio matter. In order to achieve this, artists need to develop a deeper braiding of artistic and scientific practices. Further, tapping into actual biological processes through evidence-based approaches may enable artists to operate beyond the metaphoric and symbolic concerns. Here, the presence of the living is understood through transformative parameters that open evidence-based insights capable of revealing hidden biological aspects. Chapter 4 will discuss how this was done using what this research terms an 'immersive laboratory practice' that integrates scientific methods in ways that can account for biological processes using concrete approaches.

### 3.2 Ethics, subjecthood and caring in bio art

Artists working with living matter may be required to disclose an ethical position or negotiate regulatory frameworks. For instance, this research required a formal ethics approval (via an ethics committee) since it involved working with and publicly staging living GMOs (see also Section 6.3, Appendix XXIII and Appendix XXIV). For those working with material such as

human tissue[76], animals[77] or methods such as genetics[78] this includes institutional and legal requirements that regulate ownership, licensing, welfare, 'correct' handling and disposal of bio matter. Beyond institutional perspectives, ethical ramifications of bio art, that is manipulating life for less accepted purposes (i.e. aesthetics) than scientific utilitarian agendas as highlighted in section 2.2, become more pressing as they enter the public realm. The 'most controversial type of bio art' is the 'creation of transgenic life forms' (Stracey, 2009: 498) or that where artists cross what Zaretsky calls 'the fur barrier' (i.e. working with higher animals) (Zaretsky, 2005: 5). Whilst only a handful of artists have developed a practice involving direct genetic manipulation outside of scientific collaboration, it is likely that artists and other non-scientists will be able to carry out complex genetic engineering in years to come. An ongoing concern raised by critics, is the '"deskilling" agenda' (i.e. DIY biology) that is taking place in areas such as synthetic biology that 'may finally unleash the full potential of biotechnology sparking a wave of innovation, as more and more people have the necessary skills to engineer biology' including developing 'domestic' laboratory scenarios prompting 'unprecedented safety challenges' that can be both 'messy and dangerous' (Schmidt, 2008: 1).

The alignment of bio art with modern biotechnology could be seen to be associated with the troubled history concerning the misuse of aesthetics in biology (e.g. eugenics). However, artists have pointed out that, contrary to this, they are not only challenging such presumptions but also actively engaging with the issues emerging from the biosciences. This raises several questions: How can bio art negotiate ethical challenges in the biosciences when employing the same material and methods (e.g. genetics) for purposes less instrumental (i.e. in terms of explaining, predicting and manipulating natural phenomena) to society? What are the socio-ethical implications of bio art in terms of transforming attitudes to the post-biological? Are there ethical differences between artists and scientists working with bio matter? How are bio artists approaching ethical issues of dealing with living matter as art?

A major ethical problem that surfaces when dealing with the manipulation of life for aesthetical purposes is tied to eugenic practices of the Nazis during World War II. Gessert points out that the void of bio art following Steichen's exhibition (Section 2.4 and Illustration 3) was most likely due to such consequence (Gessert, 1999: 4). The dehumanisation of the Holocaust has prompted Virilio to speak of bio art as 'A Pitiless Art' pointing explicitly to 'transgenic art' as a road to

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[76] For example, Tobie Kerridge's and Nikki Stott's *bio jewellery* (2006), Catts, Zurr and Stelarc.
[77] For instance, Kac and Zaretsky.
[78] For example, Davis and Kac.

monstrosity that eventually leads 'every laboratory to launch its own "lifestyles", its own transhuman fashion' (Virilio, 2003: 70). Gessert argues that Virilio's discussion of blending eugenics and transgenic art practices show the limited knowledge Virilio has of the field:

> Some genetic art involved plants or animals, but plant embryos did not concern him, and animal embryos held no interest except as precursors to experimentation with human embryos. (Gessert, 2010: 122).

Whilst agreeing that Virilio is raising an important issue concerning 'genetic art' as potentially aiding eugenic prospects, Gessert suggests a need for further clarification.

Indeed, we may ask: By partaking in activities involving genetics and aesthetics, is bio art softening up societies to issues concerning the instrumentalisation of life and future eugenic practices? Following Zaretsky, this terrain may already be behind us, in that a positive eugenic view[79] is no further away than advertisements on husbandry websites and proposes that with recent technologies the debate is rapidly shifting ground in that 'ethics imply humanity and the technology implies posthumanity.' (Zaretsky, 1999: 5). To which, the new media theorist Anna Munster asks:

> Is a posthuman ethics possible then, and how would it operate? Might its tentative charting be the province of bioart? (Munster, 2008: 16)

To clarify the background of this problem one need only look at how traditional anthropocentric positions are being broken down by ongoing technoscientific developments. Both the Western Judeo-Christian framework[80] and the naturalistic philosophy of Aristotle[81] privileged man's position in relation to other species. The 18th century British philosophers shifted the question from 'Do animals have souls?' to 'Do they have the requisite epistemic and cognitive capacities to have moral standing?' thus blurring the distinction between man and animal, and further questioning the fundamental morality of man (Maienschein and Ruse, 1999: 4). However, with modern biotechnology, anthropocentric notions are entering a new realm of challenges due to the exchange of bio matter (e.g. genetics and xenotransplantations) between species (including humans) and the consequent blurring of species boundaries.

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[79] 'Positive Eugenic' and 'Negative Eugenic' can be understood as two different policies, the positive view is aimed at encouraging what is seen as a genetic advantage, while the negative view discourages reproduction of what is seen as disadvantage (Häyry, 2010: 116).

[80] '[Let man have] dominion over fish of the sea, and over fowl of the air, and over every living thing that moveth upon the earth.' (Genesis 1:27-8).

[81] As part of his classification of souls through a level of sentient (Aristotle and Barnes, 1984).

The biosciences have traditionally adopted a mixture of 'environmental ethics' and 'utilitarianism' to address bioethical problems. Whilst 'classic utilitarianism is actually a complex combination of many distinct claims', broadly speaking they all suggest we should act in a manner that maximises the overall positive or good consequence for everyone concerned (Sinnott-Armstrong, 2006: 2). How these notions have become increasingly complicated follows from asking: Whom 'everyone involved' is?

'Consequentialism' or simply 'utilitarianism', a successor to 'classic utilitarianism' (Sinnott-Armstrong, 2006: 2), accounts for the acting agent's perspective, but retains an anthropocentric worldview, where 'everyone concerned' are humans either directly or indirectly benefitting from an act (Brennan and Lo, 2008: 2-3). This privileged view is broken down by recognising man as specific type of animal in the continuum of an evolving nature or life and questions any special right given to man. In the biosciences and thus in bio art, to what extent is there a need to ethically account for our dealings with non-human agents?

Attempts to include non-humans as beneficiaries became a focus for environmental ethics, an academic discipline emerging in the 1970s. At least in its early stages, environmental ethics did not necessarily take a non-anthropocentric approach but was aimed at protecting the earth's environment without giving non-humans intrinsic values (Callicott, 2005: 186). The importance of whether to assign such values to non-humans challenges our attitudes to other living matter, and is rooted in the differences between instrumental and intrinsic values as developed by the philosopher Immanuel Kant in what he describes as being 'a means to an end' or 'an end in itself' (Kant and Beck, 1997: 47). According to the philosopher Warwick Fox, understanding non-human life as having intrinsic value or being 'an end in itself' would cause a considerable shift in current ethical debates:

> […] recognizing the intrinsic value of the nonhuman world shifts the onus of justification from the person who wants to protect the nonhuman world to the person who wants to interfere with it - and that, in itself, represents a fundamental shift in the terms of environmental debate and decision-making. (Fox, 1993: 101)

The general problem with these discussions is that the distribution of values become either 'too broad and too narrow' (Callicott, 2005: 190). For instance, the animal rights activist Tom Regan places the moral limit with 'warm' 'furry' animals, the philosopher Peter Singer more 'generously' extends the limit to sentient beings able to 'experience pleasure or pain'[82] and Fox argues that all life is an 'end itself' by having their own 'telio' or goal in being 'self-creating' or 'self-renewing'

[82] Where to draw a limit between sentient and non-sentient is however contentious.

(Callicott, 2005: 189). These very values become disrupted by the post-biological through a process of blurring 'natural' categories and pushing concepts to their threshold (i.e. 'what is life?'). Several environmental ethicists draw a division between the 'natural' and the 'artificial' but privilege 'naturalness' as having intrinsic value. For instance, the environmental ethicist Robert Elliot claims that 'other things being equal, value increases as naturalness increases' and recognises most human activities as 'not natural', and further that it would be 'misleading to think of ourselves as embedded in nature just as other living things' (Elliot, 1994: 141-144). Other critics express their misgivings that the 'artificial' have any intrinsic value due to the sheer temporality associated with human activities, understandings and cultural production. The economist and writer Jeremy Rifkin, attacks not only artificial evolution (i.e. genetics) but argues that biotechnology has become aligned with postmodernism to produce a creative evolution whereby the post-biological is understood as an artistic movement:

> If nature as a whole is an evolving work of art, then our species is justifiably the ultimate artist, whose evolutionary mission is to continually shape and mold our own nature and the rest of nature to reflect our own artistic sensibilities. (Rifkin, 1998: 221)

The crutch of his argument lies is his separation between domains of techné and art. Rifkin sees the merging of these two domains as a result of postmodernism where 'technique is substituting for art' (Rifkin, 1998: 226).

> Recombinant DNA techniques are the "artists' tools" of the postmodern era. With the new technologies, human beings assume the role of artists, continually transforming evolution into works of art. This new kind of art, however, is very different from the kind of artistic sensibilities we've known in the past. It is, in a sense, a counterfeit art, in the techniques of rational calculation, mass production, and customization. (Rifkin, 1998: 223)

The argument is in line with Virilio and attempts to portray contemporary art and bio art as anything but subtle. However, the separation between art and techné is also behind us, whereas Rifkin's nostalgic notions of art is disassociated from the tools and materials of its contemporaneousness, artists have a history of actively incorporating thoughts and tools of their time. Rifkin pictures the creative evolution as a future where the natural is finally replaced by the artificial, like Elliot his value system is geared towards maintaining nostalgia for natural categories ignoring that there are no pure domains of artificial-natural or art-techné as these have already hybridised.

> It is clear that Rifkin's critique of biotechnology is rife with Christian humanist values and cannot account for the contemporary imbrication of the biological and technical. (Munster, 2008: 16)

Alongside deontological views, Rifkin's approach suggests a duty or obligation to maintain a natural sanctity and is incompatible with notions of manipulation of living matter that blur categories. The danger of this view lies in the 'natural fallacy' it commits by making the natural inherently good (i.e. George Edward Moore's 'Principia ethica'[83] and more robustly by David Hume[84]). On the other hand, there is a need to consider 'nature' as a social-construction dependent on human determination. Whilst such views are troublesome in that they suggests 'an appeal to us and our discourses as processes of justification', it views nature as something we actively shape and construct and 'that our relationship to the environment is normative through and through', and 'something we are literary responsible for' (Vogel, 1996: 9-10). Pure distinctions between domains of nature and artificial or, more broadly, nature and culture with the final leap of culture ending nature are difficult to maintain. Following the philosopher and pioneer in environmental ethics, Holmes Rolston III, 'nature is the womb of culture' and we are continuously dependent on redirecting these in 'a domain of hybrid or synthetic events [...] generated under the simultaneous control of both foci' (Rolston, 1998). Whilst it can be difficult to distinguish exactly what 'nature' and 'culture' is, Rolston suggests the notion of a spontaneous nature from which culture emerges as something cumulative and transmissible and reflects back on nature by reshaping and resourcing it (Rolston, 1998). Using the German philosopher Georg Wilhelm Friedrich Hegel's dialectic of thesis and antithesis, Rolston sees an equivalent in nature and culture harmonised in synthesis (Rolston, 1998). Another useful concept to consider is the second laws of thermodynamics[85] that describes the constant struggle against entropy, that left unchecked will return us to a spontaneous nature whatever form this takes:

> Indeed, culture is neither logically nor empirically possible without the alteration of nature. Any and all culturally-intended activity modifies spontaneous nature. But that does not gainsay the fact that there is always environing nature. No creature, humans included, can live without an environing nature. Even if we managed to end terrestrial nature, as we begin to fear in a discussion to follow, there would be the surrounding astronomical nature. (Rolston, 1998)

The biosciences' utilitarian approach offers a way through many conundrums of dealing with life as it is concerned with consequences rather than underlying duties. However, to use the same principle for bio art implies that art has a specific role in serving society, and in so, the question

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[83] Moore's argument is that 'right' or 'wrong' cannot be derived in the sense of a natural property (e.g. being yellow).

[84] In Hume's 'A Treatise of Human Nature' (Hume, 2007: 335), where he claims that we cannot derive ethics exclusively from facts but need additional ethical statements to guide facts or just because something 'is' does not mean it 'ought to be'.

[85] The second law of thermodynamics states that in any process (or isolated system) entropy increases (Roy, 2002: 154).

of whether art has intrinsic or instrumental value? What 'greater good' is bio art serving by manipulating living matter?

Some artists argue that they are providing critical insights (e.g. Jeremijenko), ethical questioning (e.g. Zurr and Catts) or being illustrative of a scientific principle (e.g. de Menezes). Despite the high-level discussions surrounding theoretical environmental philosophy, often outside the scope of lay understandings, they have had a profound impact on environmental activists (Callicott, 2005: 186, 194) but also bio artists. One need only look at the titles of such artworks to gauge how bio art is actively engaged with ethical questioning (e.g. *Nature?*, *The Eighth Day* and *Victimless Leather*) be it deontological, utilitarian or environmental.

Many have argued that bio artists should seek to avoid anthropomorphism (Fantone, 2002: 26; Catts and Zurr, 2007: 44; Gessert, 2010: 139) and take a critical stand (Reichle, 2003: 7-8; Thacker, 2003: 4; Reichle, 2007: 164) on how we formulate exchange processes with other living matter. A proposed approach to bio art could be to establish alternative yet meaningful understandings of non-human living systems. Thus, bio art has been thought to offer a way of rethinking our relationship with the 'life-world' through art. Indeed, Davis has suggested that bio art is in fact a celebration of the non-human:

> In fact much of their work deeply celebrates nonhuman life while acknowledging—even pointing to—humanity's interconnection with it. Perhaps this kind of work has the potential to do what some environmental thinkers believe is imperative: relocate humanity within the complex ecological systems of life rather than above or below it. (Davis et al., 2001: 1)

Whilst there are no agreed ethical frameworks within bio art, attitudes include those that believe their work carries no ethical problems (e.g. de Menezes, Vanouse and Kac), use their artwork to highlight socio-ethical debates (e.g. TC&A, Zaretsky and CAE) or follow more publicly accepted frameworks (Zurr and Catts, 2003: 7; Stracey, 2009: 496). Artists working with biological media through formalist artistic approaches (e.g. de Menezes) to generate visual expressions are often criticised for insufficient critical and ethical understanding of their practice in relation to the living (Kurtz, 2002: 70; Zurr and Catts, 2003: 18; Gessert, 2006; Zurr, 2008: 20). The aforementioned 2002 conference (Section 2.5.4), the 'Aesthetics of Care' (Catts, 2002), provides brief insights into ethical attitudes from key artists (e.g. Gessert, Brodyk, Zurr, Amy Youngs and Zarestsky).

Gessert suggests a utilitarian approach based on traditional practices (e.g. hunting or fishing) in view that all beings are always already manipulating each other. Adding to this, the writer and scholar Steve Tomasula noted:

> Essentially all plants and animals that are now considered agriculturally useful never actually existed in an unmodified nature. (Tomasula, 2002: 140).

The paper, 'The ethical claims of Bio Art: killing the other or self-cannibalism?' (Zurr and Catts, 2003), gives an extensive analysis on the topic and suggests that an ethical approach of producing cultural commodities (i.e. art) through the manipulation of life should follow consequential or utilitarian ethics that serves by questioning limits around sentience and what is thrown up when these are blurred.

It has been repeatedly argued that bio art engaging with the manipulation of living systems raise ethical questions whether or not intentional (Zurr and Catts, 2003: 8; Gessert, 2010: 3). For Catts and Zurr, bio art is ethically 'legitimate as long as the artist is aware of his/her motives behind the work and taking the responsibility for the consequences of his/her actions' (Zurr and Catts, 2003: 16). Further, they note that given 'the discrepancies between our western cultural perceptions and the new technoscientific understandings about life' (Zurr and Catts, 2003: 3), the role of artists should be to disclose inconsistencies. Munster has argued that bio art has already provided a substantial contribution to discussions around ethics in that:

> [B]ioartists have not only challenged the separation between ethics and aesthetics but have also foregrounded the extent to which bioethics must, in the contemporary climate, be considered more than a mere branch of applied ethics (Munster, 2008: 14).

Several artists have put forth that the living nature of bio art require artists to change their role from creators to carers (Kac, 2002: 272; Young, 2002: 69; Catts and Zurr, 2003b: 12; Catts and Zurr, 2004b: 2; Zurr, 2008: 63). Kac has further suggested that bio art in its manipulating of life opens a new chapter in the history of art, one that creates *subjects* rather than *objects*. As an art dealing with presences of subjects, Kac argues, it moves art into the realm of *subjecthood* as opposed to what art traditionally did in terms of representation, that is *objecthood* (Kac, 2007).

> Furthermore, artists whose work involves the direct transformation of living organisms or the creation of new life ought to realize that their efforts no longer take place in the well defined domain of objecthood—but rather in the more complex and fluid zone of subjecthood. (Kac, 2007)

This aspect is also featured as a central theme in Kac's works but remain highly obfuscated for reasons such as disposal of animals post-exhibition (e.g. *The Eighth Day*) and speculative use of language as in the case of *GFP Bunny*. Despite efforts, in dealing with life, bio art is frequently at risk of rubbing up against anthropomorphism, instrumentalisation and objectification of the living.

This research's use of genetics intrinsically prompts a need to consider what types of meaning processes we are engaging with. Organic living matter already has intricate systems of encoding practices that operate on discrete, behavioural and environmental levels of which there is some but comparatively little knowledge about (i.e. we have sequenced the human genome but have limited understanding of its functions). How do artists approach meaning processes in these systems?

Bio artists focusing on cultural meanings and human conditions may end up anthropomorphising living systems by mapping meanings sensible only in cultural terms. Indeed, it could be argued that artists embedding cultural meanings in non-humans do little to increase our understandings of them (e.g. Kac's 'artist's gene' in the work *Genesis* (Kac, 1999)) and only reflect our own way of being (Hayles, 2003: 12).

> The key question that repeatedly crops up here is whether they must necessarily contribute actively to the process of knowledge production in accordance with a cognitivist approach or whether their role lies in the subversive questioning of emerging concepts and dogmas. (Hauser, 2005: 187)

Contrary to this, the research's use of genetics intrinsically sought to investigate meaning processes, in the sense of biological signification, by appropriating scientific methods that enabled these to become experiential. With the primary organisms being bacteria, these have different ethical framings to the more familiar sentient and 'furry' organisms in that bacteria tend to be viewed as disease causing agents. While ethical discussions around sentient organisms focus on intrinsic values, with bacteria the debates shifts from concerns for the organisms to potential public risks. In spite of this, at least in genetics (and many traditional agricultural processes), bacteria serve an instrumental role through growth and harvesting (e.g. proteins, DNA, etc.) and while some artists attempt to challenge ethics around cells (e.g. TC&A's 'semi-living' sculptures), it is from the perspective of sentience that the instrumental use of bacteria is accepted. How then, can such approaches account for the non-human?

The use of genetics in this research provided ways of experiencing life processes in relatively simple systems, thus the use of bacteria was necessarily instrumental but for the sake of enriching understandings and experiences of such life with its underlying processes. This is aligned with Davis' suggestion that bio art is a celebration of the non-human. In addition, the research provides a transparent account for producing bio art using synthetic biology. Is then this research partaking in the aforementioned 'deskilling agenda'?

Certainly, it can be said that the research suggests mechanisms and approaches for artists to actively work with genetics, however, its institutional settings and suggested formal negotiation of regulatory frameworks is different from DIY practices this agenda commonly refers to. Indeed, this research was motivated by a more rigorous framework to achieve production and exhibition based on previous experiences with DIY. The formal approach of working meant adhering to institutional frameworks and exhibiting GMOs publicly required negotiating regulatory frameworks. While these do not deal ethics *per se*, they point back to an ethical framework that lends itself to the sciences' utilitarian, environmental and consequential approaches. Central to working within such frameworks, are potential risks posed by such material through accidental contact with humans or the environment (e.g. becoming resistant to certain antibiotics). So while negotiating these frameworks provides an opportunity to publicly exhibit and share non-human potentials, they also frame the research within a utilitarian agenda and suggest that bio art also serves an instrumental role.

Ethics in bio art is, in other words, a complex process that places demand on each artist in her/his encounter with a plethora of moral stands in the public realm. The nature of manipulation or the organisms involved often determines the ethical ramifications. Overcoming these may involve dealing with regulatory frameworks, artists who choose to do so help pave way for artists to work and exhibit such material.

### 3.3 Summary

Discourses emerging from material uses of bio art differ from thematic approaches in that the actual manipulation and staging of living matter produces a different type of presence that can prompt ethical and regulatory issues. However, and in spite of placing importance on the ethical, subjective and symbolic role of the living, bio art has paid relatively little attention to biological signification. This research suggested a need to explore this aspect more thoroughly if bio art is to bridge non-human understandings in a manner that can account for biological signification (i.e. expressions and functions relating to actual biological processes) beyond metaphoric and symbolic concerns. As subsequent chapters show, accounting for such processes requires a significant investment in scientific methods and evidence-based practices. By laying these methods and processes bare, this research provides a different approach to the 'deskilling' agenda through dealing with regulatory frameworks and evidences from production to staging such matter. Its use of bacteria and genetics shift ethical concerns from the organisms used (i.e. inflicting pain or pleasure) to the potential risks such matter poses to humans and the

environment. Publicly staging such matter requires an active negotiation of regulatory frameworks that point back to ethical approaches of the biosciences. Bio art as employed in this research can therefore be said to involve a broad range of ideas that both utilise and celebrate the non-human by debating material and regulatory framings of bio matter.

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# Chapter 4
# Art as an immersive laboratory practice: Materials and methods

## 4.1 Introduction

Limited artistic practices investigate scientific methods and materials on a molecular and genetic level (Section 2.1). Given the laboratory context of this research and its aims of using bio matter to develop artistic and experimental outcomes, its approach is necessarily aligned with the scientific practices. Hybridity is no longer situated thematically but integral to the practice. Materials and methods were to an extent the means to an artistic end, however, evaluations during the process of development were: (a) evidence-based and informed scientifically, and (b) reflective and informed from an artistic perspective.

No absolute disciplinary boundaries exist since doing science intimately affects artistic processes (e.g. reflection and visualisation). The aim was not to publish results within a scientific context; rather it was to explore how language, material and methods can extend artistic possibilities through investigating scientific processes. Disciplinary boundaries are more clearly drawn in collaboration than independent (and immersive) practices, the latter requires learning and adapting a scientific role. As such, in the case of this research, the scientific involvement was profound, challenging and time consuming. More than being embedded in a scientific culture, it was participating and understanding its material struggles. The process was one of becoming and learning to think like a scientist[86]. Immersion happens on several levels (e.g. materials, methods, knowledge and culture) and there are no clear ways of keeping these boundaries distinct. This was intensified by the lack of artists working in the same or similar settings, thus daily discussions and reflections were also contextualised within a scientific culture. These tended to be technical without reflection on any broader experiential aspects. In spite of this, and over time, there was room for acceptance of artistic motivation within the community and this provided a better ground to discuss and use the context to explore artistic ideas and materials towards art production.

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[86] In a personal discussion with Catts at Mutamorphosis II (2012), he posed the question "Are you an artist, a scientist or an engineer?" In my experience doing this type of practice blurs boundaries in a way that as a practitioner I am continuously operating between these domains.

The laboratory as a workspace protects the 'inside' from the 'outside' and vice versa. Codes of conduct in laboratory spaces may be considered restrictive to art practices, as it is typically not possible to bring in arbitrary material. To an extent, this impacted the research at least in terms of displaying artworks in that much of the materials were sourced from within laboratories. Given that materials in these settings are made for functionality, outcomes (Chapter 5) may be seen to carry a scientific undertone. In addition, bio matter comes with restrictions of handling (i.e. sterility, sensitivity and containment) necessitating a scientific approach. In terms of exhibiting such material, the aim has been to host living material appropriately while simultaneously inviting the audience into an intimate proximity.

Evidence-based process was to a large extent the methodology used, that is, adopting scientific methods to gather evidence in order to generate artistic outcomes. This was also where the practice demarcated itself from scientific research, since scientific evidence tends to involve a measurable value ideally recorded using a standard machine to generate abstractions (i.e. graphs, models, data) that are finally circulated through publications. On the other hand, this research employed evidence-based processes motivated artistically to develop reliable biological expressions that are explicitly experiential by the audience and embedded with scientific knowledge narratives.

## 4.2 Motivation and preliminaries

This research proposed that much like computational affordances (e.g. algorithms, databases, software and hardware), synthetic biology offers new potentials in the arts. Impinging on biology and informed by bio art practices, this research used living matter as its media (Section 2.1). It builds on long-term interests in art relating to genetics and, more recently, synthetic biology, established through an art practice with C-LAB (Section 1.2 & 2.5.4). Experiential outcomes of scientific projects emerging from synthetic biology, in particular through the iGEM competition, was a motivating factor to drive the practice towards an immersive laboratory engagement.

A series of conferences, discussions with key stakeholders and self-study along with a DIY practice played a role in formulating the background for the research. For instance, as mentioned in Chapter 1, this included participating in a key UK conference 'Synthetic Biology: Discussion meetings' (The Royal Society, 2008); communication with founders and organisers[87] of the iGEM competition to join as an unconventional participant (i.e. as an artist); self-studying

[87] Tom Knight (BioBrick™ / MIT), Pam Silver (Openwetware) and Mathew Cowell (Partsregistry).

using the textbook "Biology" (Campbell and Reece, 2008); and carrying out a number of kitchen-based experiments towards developing artworks that included bacterial transformation (WARD'S Natural Science, 2006), plant tissue culture, DNA extractions and chlorophyll purification (Boland, 2004; Cinti, 2004; Cinti, 2007).

In spite of efforts, operations were limited by access and did not encompass more ambitious aims of production. In particular, this became clear through the project *The Martian Rose* (Boland and Cinti, 2007/2009) where living roses were exposed to Martian conditions by taking advantage of scientific collaboration and laboratory access. These developments encouraged and brought about a need to (1) establish a more formal context of scientific operation and (2) begin to develop a stronger adherence to scientific practices in order to produce art. Partly, this comes from a growing critique around the process of making bio art: unless artists develop an understanding of material and methods enabling them to do the work, there is a danger of ending up with 'readymades' or material that has simply been borrowed or appropriated from the sciences (Section 2.3-2.4).

Coming into this research, scientific evidence-based processes were used to design, develop and analyse outcomes. How such methods become assimilated into artistic practices and whether they are understood as scientific or artistic must be seen as a transdisciplinary challenge relating to the schism found between disciplines (particularly in institutional settings).

This study was primarily concerned with the production of bio art in a laboratory context; however, the development, dissemination and staging of artworks were integral parts that needed specific attention given the critical debates (Section 2.1) surrounding GMO and bioethics (Chapter 3 & Chapter 6). As outlined in section 2.4, artists have approached the field of bio art from many different perspectives and there is a great deal of variety in materials, methods, motivations and outcomes that impact how bio art is done.

When considering appropriate evaluation of tools, a primary variable is the scientific or biological matter at hand. As a hybrid discipline, bio art, in its methodology impinges on scientific practices and artists are therefore expected to adopt scientific methods. On the other hand, the sheer range of modalities (e.g. performative, DIY, bio-hacking, scientific deconstruction, etc.) and types of material indicates that there is no standard approach. Adding to this discursiveness is also collaboration, or use of natural or borrowed material (Section 2.3).

### 4.3 Ontological braiding

Chapter 3 proposed that in order to move beyond metaphorical use of living matter, bio art practices need to investigate biological processes in the living by tightly weaving artistic and scientific understandings. To achieve this, the research grafted scientific methods onto an artistic practice in a manner that accounted for biological signification. As a particular synthesis of art and science practices, it suggested a different mode of bio art that has ontological implications.

While philosophical background for ontology can be said to deal with existence, the mode of being or form (Hofweber, 2012), both scientific and artistic ontologies can be understood from a multitude of positions beyond the scope of this thesis. For the purpose of this research, ontological questions emerging from the science have to do with its disciplinary belief system that there exists a 'real truth out there'[88] that can be described through theory in acceptable manner to form a 'true story of what the world is like'[89] (Van Fraassen, 1980: 8). To ask such an ontological question within the arts may seem ill advised given the changing and varying cultural dispositions, but the question of what makes something a work of art is part of an ongoing debate. Many would agree, as noted in section 2.4 in discussing art-science versus science-art, that it is the intentionality of it being an artwork that justifies its nature (e.g. Eaton, 1969; Iseminger, 1973; Dutton, 1979; Hilpinen, 1992; Hilpinen, 1993; Thomasson, 1998; Levinson, 2006). On the other hand critics have argued that a work cannot be judged on the basis of the authors' intention (since it cannot be fully known), rather it should be judged through the experience in a specific instance in the public (Wimsatt Jr and Beardsley, 1946).

The ontological question emerging from the material approach as employed by this research was: What are the implications of bringing these two ontological positions into contact?

As we have seen (Chapter 2 & 3), this research applied a specific grounding in background theories of bio art. Thus, it reflects on the ontological conditions of bio art as an art practice having a preoccupation with bio-scientific material. Expanding on these, it suggested that incorporating a deeper scientific understanding could open the field to a broader set of biological expressions concealed from our usual sensory experiences. The central proposition in achieving this was through an evidence-based practice that employed scientific methods to corroborate

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[88] My quotes. Also referred to as scientific facts being 'out there' (Latour and Woolgar, 1986: 175).

[89] This position, called 'scientific realism', tends to be the common perspective within the science in spite of alternative sociological analysis of how science succeeds through inventive interactions with reality rather than a world of beliefs (Knorr, 1977: 672-674; Latour and Woolgar, 1986: 175).

evidence. Thus, the ontological braiding of this research was such that it developed an art practice that incorporated scientific methods in an evidence-based manner to draw out telling expressions about underlying processes in the living, which could both be evidenced and experienced. The implications of connecting these aspects generate a different type of presence that expands on understandings of the non-human.

### 4.4 Immersive laboratory practice

Several art-science research organisations (e.g. SymbioticA) have established their own set of protocols and developed workshops (Cinti, 2005; Cinti, 2011b) that unequivocally encroach on scientific methods (Section 2.5.3) and highlight the cultural clash experienced by artists when entering scientific laboratory settings for the first time (Catts and Cass, 2008: 143-147). It has been precisely because of such challenges of navigating oneself through a vastly entrenched and ramified knowledge field that most artists approaching bio art have done so by collaborating with scientists (e.g. Kac, Davis, de Menezes, Zaretsky, see also 2.3).

This research took an independent approach that in a collaborative engagement would have otherwise been undertaken by scientists. It is therefore useful to look at the different insights offered by independent research versus collaboration.

Collaboration is an encouraged form of working as it offers an exchange between knowledge domains but suggests a schism between disciplines retained by the division of work with expertise in separate areas. Advantages of collaboration are far reaching since it suggests a synthesis between disciplines that is more than the sum of its parts. There is no doubt that artists working with experts in a particular scientific field, can readily re-deploy or generate output at a rate that would be challenging for artists to do on their own. Questions arising from such division are nonetheless important due to the different role artists, scientists, artworks and scientific knowledge have in the public domain. Do we consider artists engaging with scientific knowledge processes through collaboration as experts in the related scientific field? What is the knowledge threshold for the public to engage in the science and how are artists filling this gap? And should scientists be included as authors of collaborative artworks? A challenge in art science collaboration is establishing a mutually beneficial working relationship[90] (Section 2.3). As a social enterprise, it may take time to establish good relationships and develop shared understandings,

[90] Avoiding models where artists are merely used as decorative designers and scientists as technicians.

however, such collaborations stand a better chance of effectively tackling these questions (e.g. as opposed to fulfilling funding criteria or institutional agenda).

Many bio artists have been critical of relying on collaboration alone as an approach to produce bio art (Kac, 2007). It has been argued that there is a need to develop an independent practice to handle material in order to gain a better understanding of knowledge processes and to take responsibility and ownership in manipulating living matter (Catts and Bunt, 2002: 2). For such practices to be established, artists will need to adopt a hybrid skillset for creating materials and employing methods. To evaluate a hybrid practice one must therefore consider how they combine and contribute between disciplines – as the knowledge gap they address is located therein. For an independent art practitioner this involves a scientific overhead but provides more equal footing with science researchers and opens a shared space between disciplines by literally attempting to hybridise.

Overcoming limitations requires artists working independently to acquire scientific knowledge processes, language and methods, and situate a context to provide material and operational access. This research involved a lengthy immersive laboratory practice, an appropriate method to undertake such work.

The process of immersion allows practitioners to experience an environment as a totality by being engrossed in it. Immersion as a method for learning second languages has been appropriated for about forty years (Cummins, 1998) and it is useful to understand this practice within this context. This involved an independent daily laboratory practice and was the core undertaking in the first two years of the research. An extensive learning process was carried out in the first year and was driven by reflecting on potential artistic outcomes. Evaluation and development of specific projects was underpinned by evidence-based scientific practices. The second year evaluated outcomes that modified artistic aims and expanded the practice to address more specific areas of research (e.g. working with synthetic biology), and the third year focused on outputs and exhibiting artworks.

The following provides an outline of institutional arrangements and learning mechanism, before going through specific laboratory methods relating to recombinant methods used to develop works leading into more specific use of synthetic biology.

### 4.5 Institutional arrangements

Prior to initiating the research, the School of Media, Art and Design assisted in organising a scientific supervisor and laboratory bench (Illustration 9) at the School of Life Sciences (SLS). Being the first research of its kind at SLS, no formal financial arrangements existed between the schools prior to the research and there was a need to be catalytic for both parties to communicate and establish the necessary conditions for the practice to begin. Since doing science is expensive, as it requires not only reagents but also access to specialised equipment, the likelihood of additional funding being needed as the work progressed was a potential barrier for an immersive practice. The field of synthetic biology has only emerged in recent years and no specific expertise existed at the University of Westminster but this research relied on expertise in adjoining fields (e.g. molecular and recombinant biology).

Illustration 9: The laboratory space used for the duration of research included standard equipment needed to undertake molecular laboratory work. Photo: Howard Boland.

### 4.6 Suggested learning mechanics

Mindful that the first period of working in the laboratory would be disorienting, a guiding question was: How can the research achieve its aims while getting to grips with synthetic biology? From the outset, synthetic biology's engineering approach offered a programmatic

manner of thinking about genetics. Given my post MA (MA Digital Practices, University of Hertfordshire, 2002) background as a bio art practitioner and a professional creative programmer (Section 1.2), it seemed plausible that a connection could be consolidated through synthetic biology that combined generative approaches of producing art with living matter. Using one discipline to learn another had previously been achieved by drawing on my background in mathematics (University of Oslo, 1998) to establish competency in computer programming. As a programmer, whether a professional or an amateur, learning is an ongoing exercise and there is a continuous need to keep up with technologies seemingly in perpetual motion. A useful way of dealing with coding challenges within specified timeframes is to locate solutions by re-mixing snippets into an integrated whole. In this context knowledge is fluid, contingent and dependent on tasks to generate a bricolage of elements that help produce a structure.

Based on these underpinnings and thinking of synthetic biology from the perspective of learning a programming language, my approach suggested using a series of tutorials derived from Rice University (US), which specifically focused on core practical aspects of synthetic biology with demonstrative visual outcomes, intended to provide practical insights and reflect on qualitative characteristics of the material in terms of art. The tutorials included foundational methods in synthetic biology and molecular biology such as sterile techniques, preparation of media, growing cells, introducing foreign DNA into cells, extracting DNA, and assembling DNA fragments. My aim was to learn these methods in order to understand how to create novel genetic circuits with the intention of producing experiential outcomes.

Underlying these methods is the central dogma of modern molecular biology (Figure 4) describing the flow of information in biological systems as the production of material through a process of transcription and translation of genetic code (Crick, 1958; Nirenberg and Matthaei, 1961; Crick et al., 1976).

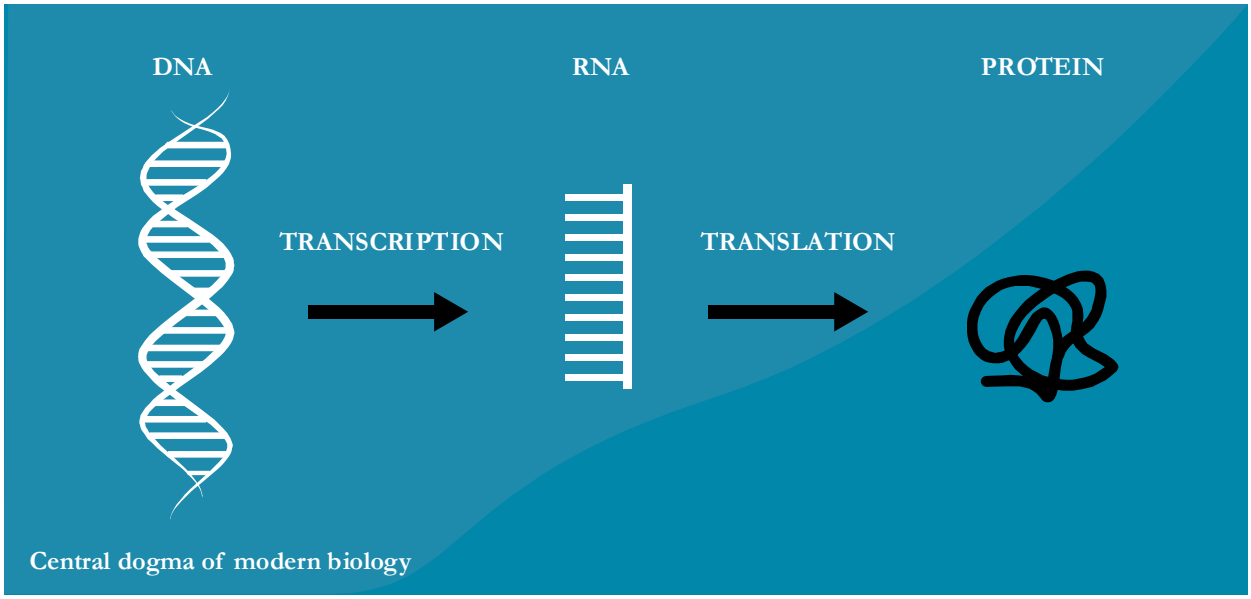


Figure 4: Central dogma of modern biology where the flow of information from DNA to proteins happens via transcription and translation of RNAs. Illustration: Howard Boland.

Despite shared symbolic connections between the virtual and biological found in the concept of code, these systems have different ontological, epistemological and material foundations and cannot simply be reduced to the same category (Section 2.3). Synthetic biology does however attempt to bring these ideas into proximity by producing greater behavioural predictability in biological systems. So while synthetic biology includes computational thinking, the material foundation of biology is such that a practitioner must learn how to handle biological laboratory practices.

The initial phase involved microbiology and molecular recombinant methods (discussed in Section 4.15 and 4.12) and explored growth and visualisation of fluorescent expression. Based on findings and learning, the practice was extended toward developing more specific artworks.

## 4.7 Towards an independence practice

Introduction to the laboratory practice was supervised during a one-week period in December 2009 and briefly covered molecular methods described in section 4.12.1 - 4.12.5. For instance, it involved orientation of the premises, basic 'house keeping rules' (e.g. washing, storage, equipment, entering and exiting the laboratory, etc.), sterile techniques, pipetting, preparing Lysogenic broth (LB) media, preparation of petri dish plates, use of antibiotics, transformation, growing bacteria on plates, extraction of plasmids, running agarose gels and visualising DNA using a UV-documentation station (Illustration 10).

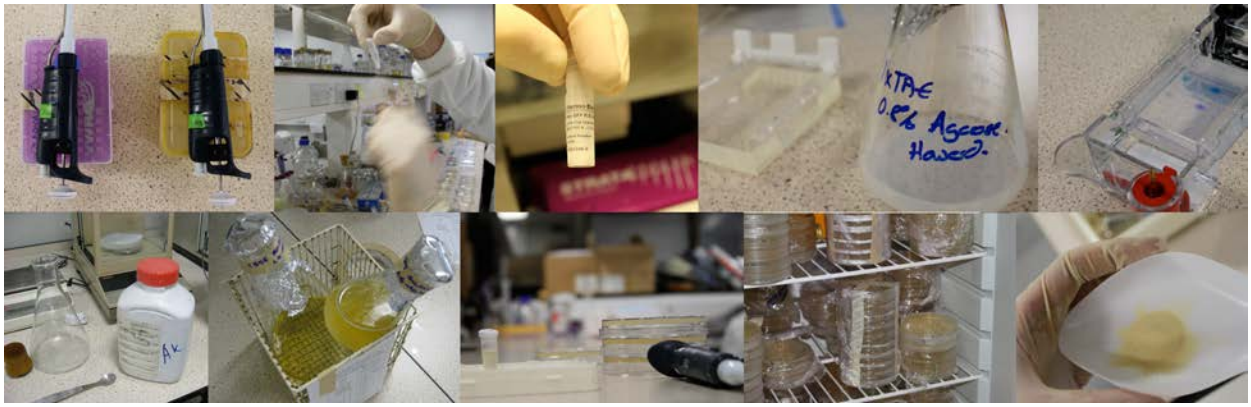

Illustration 10: Initial period in laboratory involved getting to grips with both basic techniques towards an independent practice. Photo: Howard Boland.

The subsequent independent learning period expanded on preliminary methods (Section 4.12.8-4.12.13) to manipulate DNA providing a full cycle of the process. Limited material was available and modifications of tutorials (Section 4.6) were made to accommodate for material discrepancies. For instance, only a single plasmid (pMAK512)[91] was available to explore recombinant methods and a budget was still to be established. Material was either taken from past doctoral students or borrowed from researchers in the laboratory. Since laboratory members were concerned that having an artist working in this space (discussed in Section 5.5) could impact their research (e.g. by contaminating material), efforts were made to lessen dependency on generosity and this involved producing material needed in the practice (e.g. preparing competent cells).

Preparing scientific material from the ground up served a two-folded role; (1) it provided the material means to do the work and (2) placed the practitioner in an independent position that gave a sense of ownership as a result of the technical understandings of sourcing material. This also points to an 'overhead' for artistic practices as the artistic processes are generally not understood as producing 'generic' scientific materials[92]. For instance, bio art workshops focus on the artistic potential and leave out the production of materials so artists only see 'final steps' (Section 4.4).

## 4.8 Material underpinnings of molecular biology

The 'overhead' of understanding the material underpinnings of practical molecular biology and develop independency, marks a significant change in how artists approach the field because it

[91] Provided by Anatolyi Markiv, University of Westminster.

[92] For instance, it is possible to purchase commercial competent cells (e.g. NEB, Invitrogen).

involves routine scientific practices such as replenishing material and building layers of components that can be trusted. Since molecular laboratory work involves layering processes using mixtures, these processes cannot simply be undone or modified later, and further, any suspect sub-components throw into question results ahead (both positive or negative). This is a radical departure from computer programming where it is more common to have access to modify elements in a non-linear fashion. Another analogy often used is that of the preparation of food (e.g. cooking or baking), since this is a common way in which we apply organic mixtures of material in a series of steps to create layered outcomes. However, relating molecular biology to cooking come with many obvious problems such as our inability to taste and observe processes and further the minute quantities used and the way of handling biological material is significantly different. In other words, molecular laboratory work suggests a stringent need to scrutinise material at hand with few direct guidelines from other practices. In this context there is also less room for approaches inherent in the arts such as those introducing unintentional elements or chance and it is often more conducive to explore these at later stages once the evidence gathering reaches an appropriate level of complexity (whatever level the practitioner is gauging at). In particular, the technical challenge of producing evidence and a sense of control on a biological level is of great importance not only to drive artworks or experimental practices forward but in terms of the sort of outcomes we can be expecting from artists and the resources we need to invest in these processes. For now, it suffices to say that a push in this direction enriches the research-based artist's ability to clearly communicate across domains, which in turn uncovers his or her capacity to take part in innovative research contexts.

## 4.9 Understanding genetic components

This section provides a brief and accessible overview of central components to clarify concepts throughout this and subsequent chapters.

Genetics involves a ramified network of interactions that are challenging even for professional scientists since it is difficult to predict specific components and pathways responsible for observable characteristics (or phenotypic expressions). Characterisation of components into well-defined actors in the network is understood as treasurable knowledge in molecular biology. When uncoupling genetic components from a natural system, it is not a given that these will operate in any other system nor that they will function in synthetic circuits. Entering from the side of art, the knowledge area is densely packed with jargon and cannot readily be comprehended. While the dogma of molecular biology (Section 4.6) provide top-level

understandings, this research needed to shift its viewpoint to unpack how genetics operates on the level of components (Figure 5). Using a basic computational model, one way of looking at this, is to consider what inputs trigger outputs. Thus, an initial question asked was: What tells the genome to produce proteins? One answer is found in specific sequences or components regulating transcription, known as promoters.

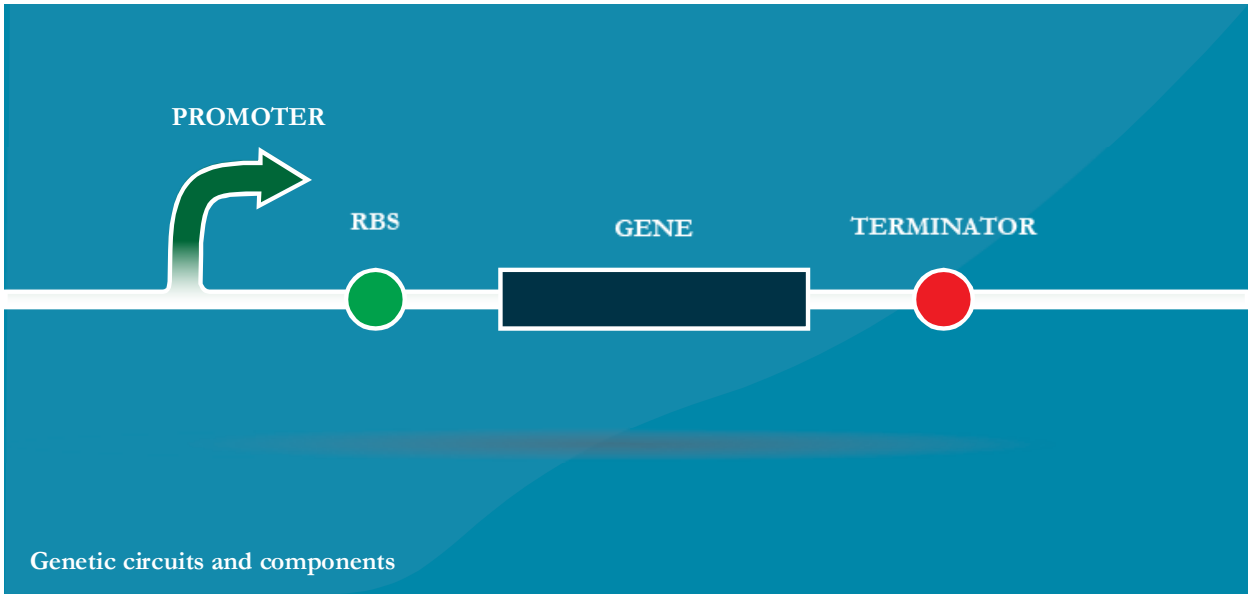


Figure 5: A generic genetic circuit normally includes a promoter, ribosome-binding site, a gene and terminator. These components are the most common in synthetic biology and were used extensively in this research. Illustration: Howard Boland.

### 4.9.1 Promoters

Promoters respond to environmental and internal signals through chemical interactions known as transcription factors. When these interact with promoters, they modify access to the DNA by blocking or enhancing polymerase's (i.e. an enzyme) ability to bind and transcribe the DNA. Another way of thinking of promoters is to consider these as switches that either allow or block flow of current (i.e. polymerase) through a circuit (i.e. DNA). For instance, this research employed a promoter that becomes active during oxidative stress in the works *katE* and *Stress-o-stat* (Section 5.6 & 5.7).

### 4.9.2 Genes

The role of promoters is to control expressions of sequences known as genes (or coding genes sequences) that become transcribed and translated into proteins. For instance, in this research reporter genes were used to produce red and green fluorescent proteins (RFP and GFP, Section 5.6). However, genes can produce proteins with a multitude of functions such as enzymes

capable of converting chemical products (e.g. an alcohol into an ester as in the work *Banana Bacteria*, Section 5.8).

### 4.9.3 Ribosome binding sites & terminators

When building genetic circuits two more components are normally taken into account to ensure efficient conversion from genes into proteins. The first is known as ribosome-binding site (RBS) and is a short sequence preceding the gene that improves the ability for translation to be initiated. Conversely, terminators serve to efficiently disconnect translation. Together these four components (i.e. promoter, RBS, genes, terminators) form the basis of most common circuits in synthetic biology.

### 4.9.4 Restriction sites

Restriction sites play a key role in assembly of DNA since they can be recognised by restriction enzymes enabling DNA to be cut. A site is normally around six base pairs and provides a unique signature specific to an enzyme. In a natural environment, this can be thought of a protection mechanism against foreign DNA, however, in genetics they are key components that allow engineering to take place.

### 4.9.5 Plasmids

A common way of introducing circuits into organisms relies on using plasmids or vectors. These can be thought of as circular pieces of DNA co-existing independently of the genome. It is possible to produce more complex circuits by cutting and joining DNA to add additional parts to plasmids. However, two additional components are central for these to operate in a functional manner (Figure 6).

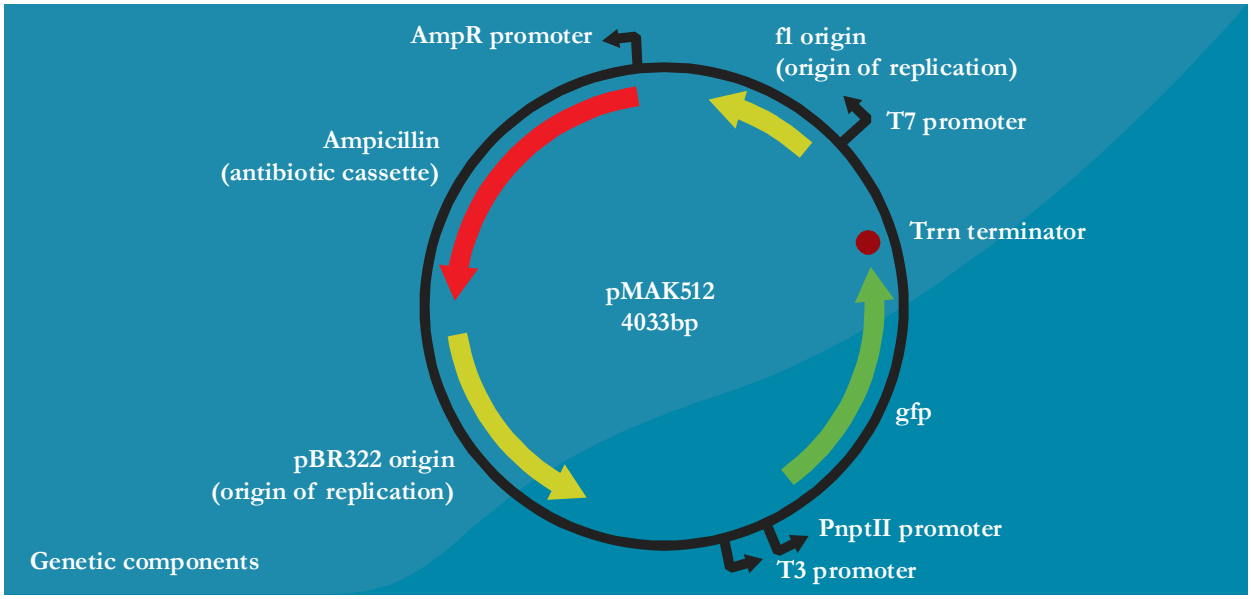


Figure 6: Example of components in plasmid pMAK512 (a plasmid used early in the research). Of particular importance are the origins of replication governing the number of plasmids copies produced and antibiotic cassette (e.g. Ampicillin) allowing selection. Illustration: Howard Boland.

### 4.9.6 Origin of replication

Since plasmids also divide and multiply, a component known as the 'origin of replication' provides the initiation and controlling mechanism for when and how often plasmids can replicate inside a cell. According to where this origin was extrapolated the number of plasmids produced per cell can range from thousands to only a few.

### 4.9.7 Antibiotic cassettes

Like 'origin of replication', antibiotic cassettes are standard components found in almost all stabile plasmids. The notion of a cassette refers to an integrated part containing RBS, gene and terminator. A promoter driving the expression of these enzymes allow cells containing such plasmids to breakdown antibiotic chemicals otherwise detrimental and ensure that only these cells survive (or become selected).

### 4.9.8 Primers

To conclude this section on genetic components, it is useful to grasp the idea of primers since these were used extensively. Primers are small nucleotides sequences synthesised by commercial companies used to extract larger sequences of DNA either from the genome or plasmids. Since polymerase transcribes DNA in one direction on each strand, the primers are designed to be identical to the beginning and end of the target sequence to be extracted (Figure 7). To ensure

unique binding, primers need to be sufficiently long (e.g. 18-22bp) and operate at an acceptable temperature (annealing temperature of 52-60ºC). Using what will later be described as a polymerase chain reaction, primers allow polymerase to attach and transcribe the desired sequence through a cyclical process generating a large amount of this material.

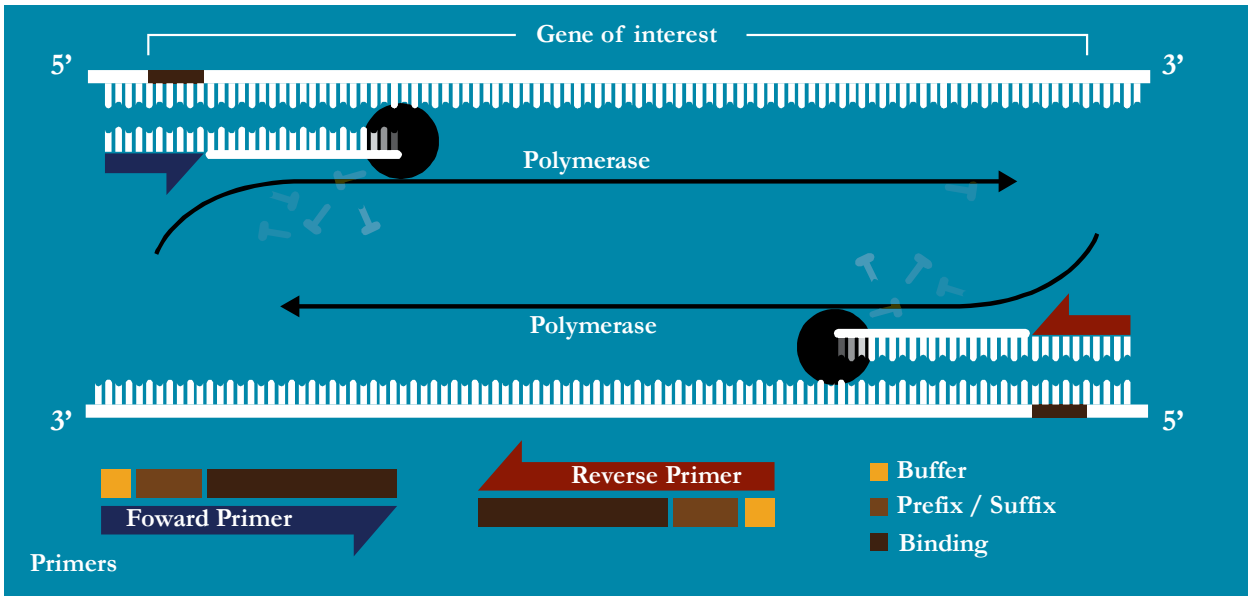


Figure 7: Primers are short nucleotides synthesised by commercial companies and used to amplify DNA. When designing primers, a buffer (2-4 base pairs) is normally added to adjust for inconsistent binding, this is followed by a prefix or suffix (depending on forward or reverse primer respectively) consisting of restriction sites, finally, the primer binding sequence is an actual identical sequence to the target sequence. Illustration: Howard Boland.

## 4.10 Obtaining material

Sharing policies within the science community is generally good, however an official agreement of material exchange between institutions known as material transfer agreements (MTA) is often needed. MTAs can take a substantial amount of time to organise, which was sometimes the case in this research. For instance, in the work *Bacteria Light Sensor* (Section 5.10) one component (a plasmid) was under this protection and was not obtained. Additional obstacles come when researchers change institutions making it difficult to trace material. These factors play into one of the advantages of synthetic biology, in terms of having a central repository of materials (but it does not address specific material needs).

### 4.11 Bioinformatics

Preparations leading up to the wet laboratory work involve researching scientific papers[93], online databases and software to simplify calculation or search tasks. For instance, the National Center for Biotechnology Information (NCBI) was a substantial resource to locate well annotated genomic sequences with references and has a rich set of tools to manipulate and view data. This was used to locate genetic components and extract sequences (Illustration 11).

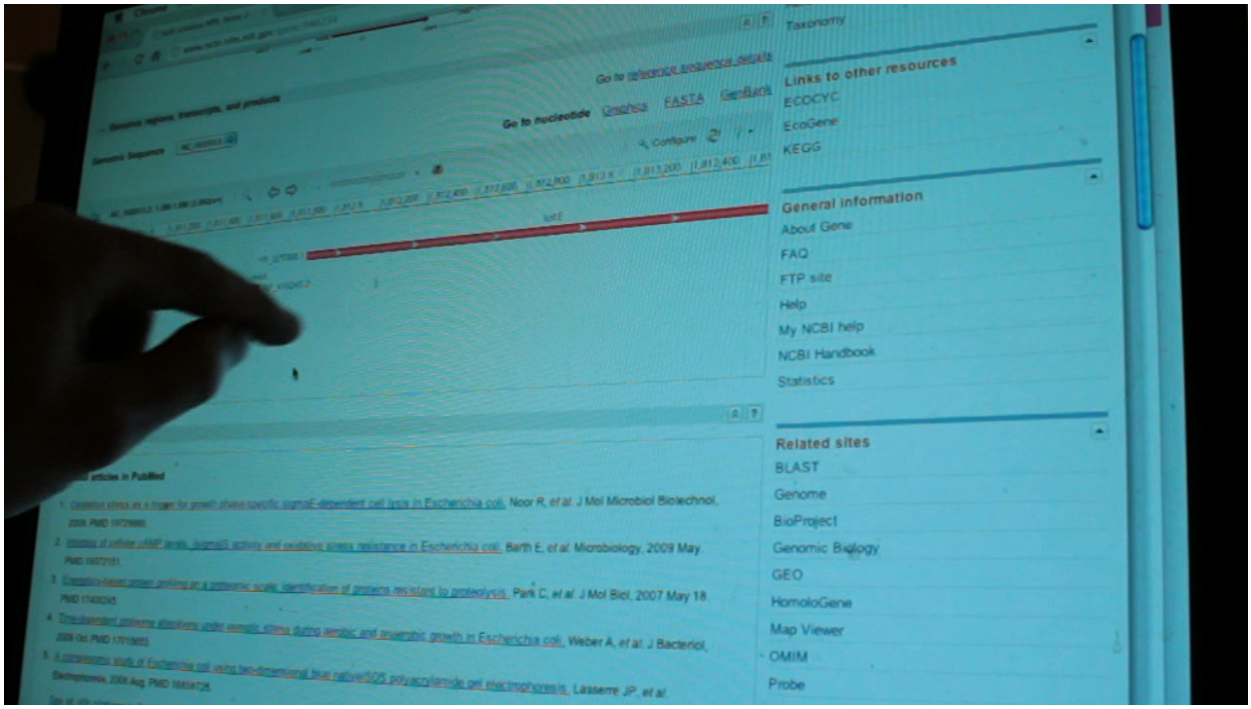


Illustration 11: Photograph showing process of working with the NCBI database to locate a sequence region used in the work *katE* (Section 5.6). The NCBI database provides an extensive set of tools for locating genetic components and designing materials (i.e. primers) towards physically accessing these. Photo: Howard Boland.

Primer design is then used to generate signature sequences (primers) using software commonly based around a core engine known as Primer 3 (Untergasser et al., 2007). Restriction sites are normally added as an extension to primers in order to be compatible for assembly. As part of this it was ensured that none of these sites were found inside the sequence, as cutting the desired product would cause unwanted fragmentation. Software known as NEBcutter II (Vincze et al., 2003) can be used to check for sites. If present, it may be desirable to remove these using site-directed mutagenesis resulting in a base change. Based on these procedures, a primer sequence can be ordered and synthesised by a commercial company (e.g. Invitrogen). Some programs (e.g.

[93] The accessibility of science papers remains challenging for novices given the level of technical language and jargon used. Similar to appropriate methods from the sciences, getting to grips with this language adds to the investment for undertaking an immersive art practice.

Geneious) allow cloning processes to be simulated *in silicon* by allowing PCR products to be generated, digested and ligated.

A second use of bioinformatics in this research was the analysis of sequence results following laboratory work. A commercial company normally performs the sequencing of a construct or a component. The returned sequence information (one for each direction based on primers) is cleaned up using software such as FinchTV (Geospiza, 2011) by selecting optimal portions of each sequence (Illustration 12). By combining these two sequences into a consensus sequence the original designs (e.g. using databases) can be consolidated with the outcome of laboratory work.

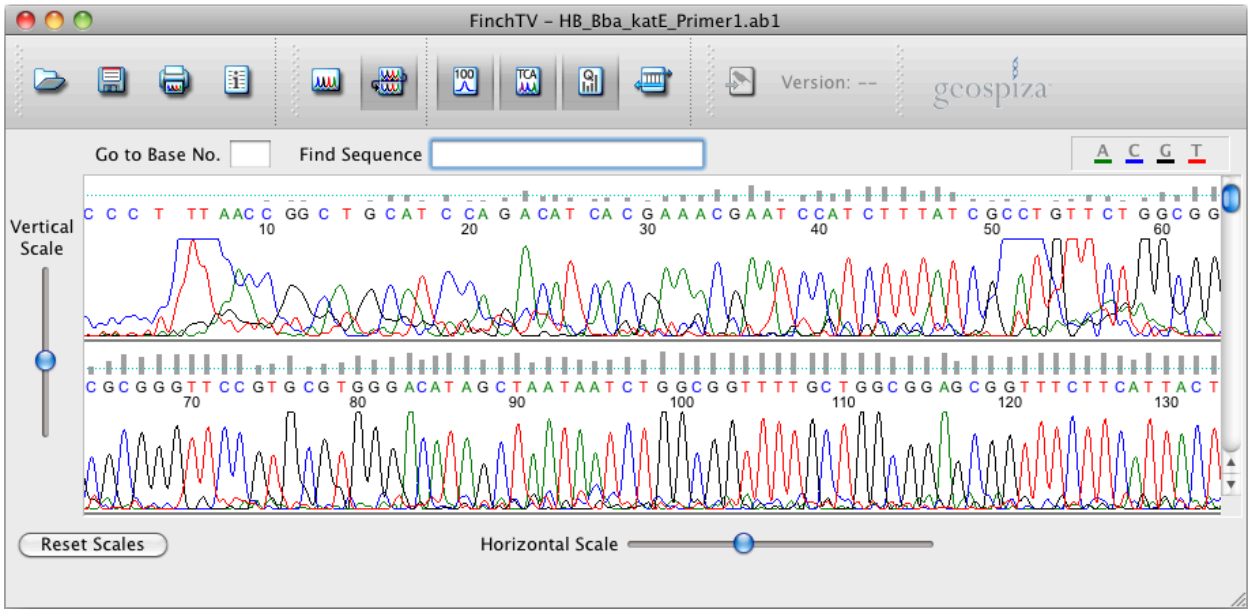


Illustration 12: Screenshot from sequence analyser (FinchTV by Geospiza) with open sequencing file from the project *katE* (Section 5.6). As can be seen in the graph, sequences tend to give less reliable reading at the beginning (and end) of a reaction, and it is useful to exclude this information when generating a consensus sequence.

## 4.12 Molecular and recombinant methods

The use of evidence-based processes involves a series of iterations in terms of learning, optimisation and layering to build up a picture that corroborates the scientific aspect of the work. To leverage the use of reference and detail it is appropriate to outline these methods as they were continuously used throughout the research. The diagram (Figure 8) provides a brief overview of the workflow highlighting the major steps in the laboratory work. As indicated, these processes often result in sequencing information used to align laboratory work (i.e. material) with bioinformatics (i.e. information). While the diagram suggests multiple checkpoints using visualisation of gel bands, many of these steps can be skipped as practitioners become

comfortable with the material and more so by approaching the recombinant through synthetic biology (Section 4.14). Further, it is worth noting that during the course of the research, many new methods[94] emerged that drastically simplify the described steps. In what follows, I will therefore outline methods of introducing foreign DNA in bacteria, growing bacteria, extracting DNA and assembling new constructs using enzymatic processes by cutting and repairing DNA fragments.

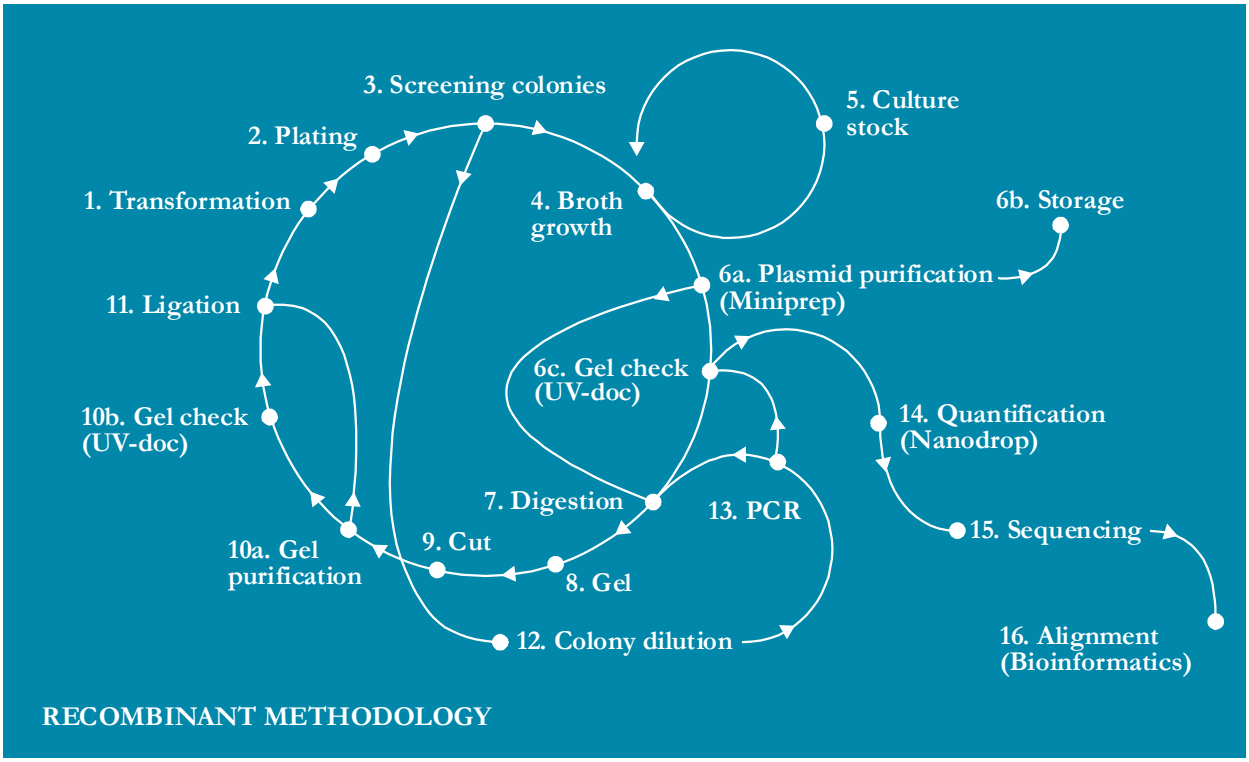


Figure 8: Recombinant methodology workflow of laboratory work involving iterative and time-consuming processes, aimed at generating genetic constructs that are continuously debugged using gel analysis and finally verification by sequencing. Illustration: Howard Boland.

### 4.12.1 Transformation

To introduce foreign DNA (plasmids) into bacteria, a process known as transformation is commonly used. While this can be done using electroshock, this research employed heat-shock as a method (Appendix VIII). Specially prepared cells (competent cells, Appendix I) susceptible to uptake of (plasmid) DNA were thawed and supplied with a small amount of DNA (eluted in water). A brief heat shock makes cell membranes more porous allowing DNA to enter. Cells

[94] Notably, recent advances in assembly technology (e.g. Gibson assembly, USER cloning or Plug n' play, and Golden gate) have focused on finding new methodologies to overcome the above schema, however, many if not most of these steps are still the most common methods used in most research laboratories.

were recovered by shake-culturing these in optimised broth (Super optimal concentrate, Appendix II.IV).

4.12.2 Plating

Once transformed, cells were transferred onto agar plates containing selective media using glass beads. The method provided a uniform spreading to encourage separate colonies to appear by growing these on a selective antibiotic. For *E. coli*, this was done overnight (16hrs) in a 37ºC incubator.

4.12.3 Screening colonies

Each colony is considered to harbour a consistent set of genetic material (e.g. plasmid). Colonies were commonly screened for two reasons: (1) to amplify genetic products using PCR, or (2) to produce more DNA by growing it in selective liquid broth overnight.

4.12.4 Broth growth

Broth growth was either done to harvest DNA, subculture or increase culture volume, or to prepare long-term stock. Harvesting DNA is made possible since plasmids are copied along with duplication of cells. Like plating, broths used selective antibiotic and in the case of *E. coli* cultures were grown overnight at 37ºC in a shaker.

4.12.5 Culture stock

From cultured broth it is common to store small aliquots of a culture by supplementing glycerol (a mixture commonly known as glycerol stock, Appendix XIV). Stock samples were stored or cryopreserved at -80ºC for indefinite periods of time.

4.12.6 Plasmid purification

Harvesting plasmids from overnight broth culture is commonly done using commercial kits[95] and the process is referred to preparing a 'mini-prep'. Cell pellets were collected by centrifugation and re-suspended in a small solution containing an enzyme (RNAse). By lysing or disrupting in a timed event, plasmids released, before being stopped by providing a neutralising solution causing other components to precipitate. High-speed centrifuging was used to separate plasmids from cell-pellets making it possible to bind DNA to a filter column before washing these in a series of

[95] For example, Invitrogen or QIAgen plasmid purification kit.

steps and eluting the plasmid from the column into a tube by adding water (Appendix IX). Purified or digested plasmids were stored in -20ºC for later use.

### 4.12.7 Gel check and preparation

Agarose gels (Appendix VII) were used to confirm the presence of DNA after plasmid purifications or PCRs. If the plasmid DNA is linearised, a gel can provide information of its size (given in number of base pairs) and the amount of DNA. Agarose gels can be prepared at various densities depending on the fragment size but most common are 1% and 2% gels, where the former is used for larger fragments and the latter for smaller. Agarose gels contain a mixture of agarose powder and a buffer that is heated, cooled and then casted into a tray containing a comb. The comb is later removed leaving behind wells, the tray fitted into a tank and flooded with the buffer. DNA is mixed with a heavy loading buffer containing a dye and transferred into the wells (Illustration 13). Using a powerpack, a constant voltage was supplied across the gel, making the negatively charged DNA migrate towards the positive side of the gel. As a measurement ladder containing fragments of DNA became separated into bands of specific size and amount during migration. The loaded DNA also separated and after a period (e.g. 1 hour) the electricity was disconnected. A fluorescent agent, Ethidium bromide, was added to the gel and intercalates with the DNA making it visible under UV-light. A UV-transilluminator fitted with a camera was used to document the gel.

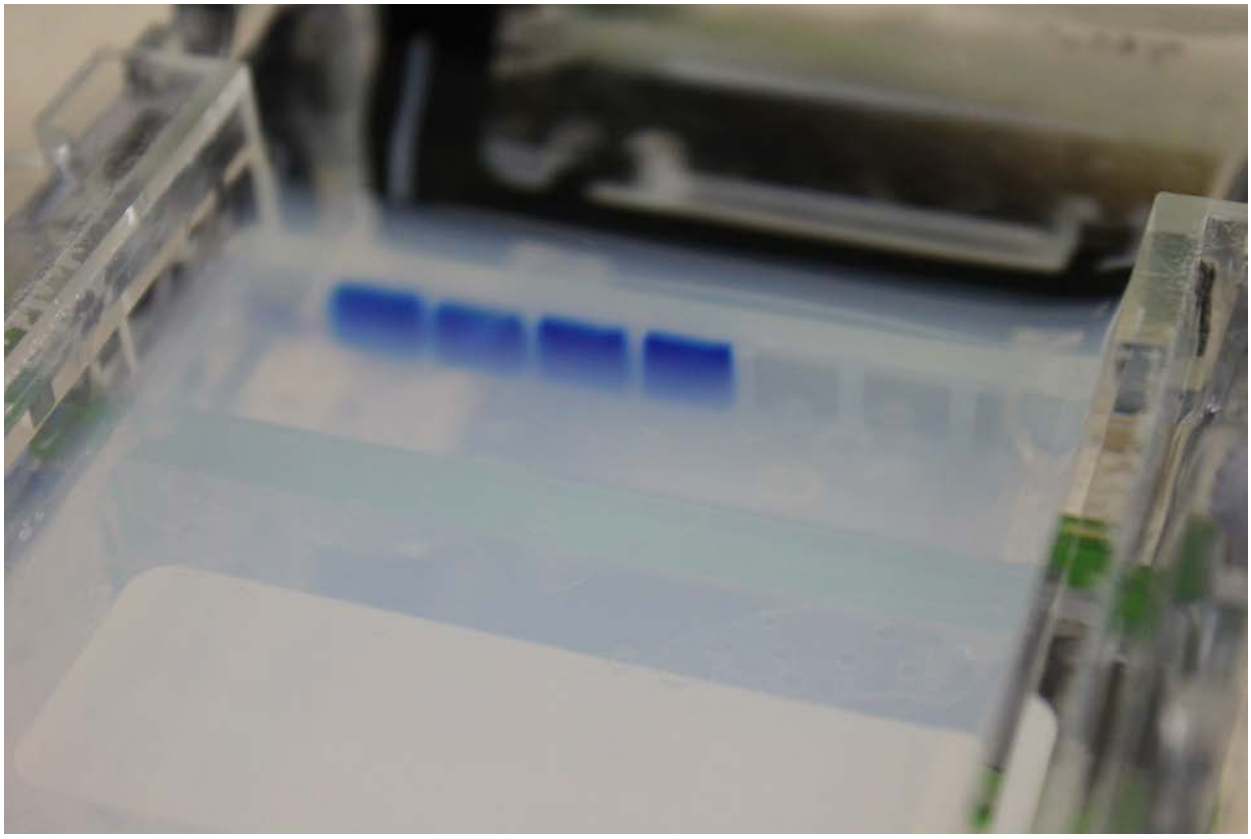

Illustration 13: Agarose gel with loaded DNA samples. The gel is submerged in a buffer (Tris-acetate) and electrical current flows through allowing the negatively charged DNA to move towards the opposite (positively) charged side. Photo: Howard Boland.

### 4.12.8 Digestion using restriction enzymes

To separate DNA into fragments for the purpose of assembly, restriction enzymes were used to cleave restriction sites (Section 4.9.4). Normally, a fragment is cut with two enzymes (double digestion, Appendix XII.III) producing overhanging sites on each side. In doing so, it was possible to cut a specific product, such as a gene, out of a plasmid, resulting in a gel showing two bands. A single digestion on circular plasmids yields linear plasmids and enabled confirmation of size using gel electrophoresis (Appendix XII.II). In cases where double digestions were problematic, a sequential digestion could be used to control and ensure digestions reactions were completed. This involved first using one enzyme, purifying the DNA from the gel slice and then applying a second enzyme (Appendix XII.IV). Digestion reactions make use of restriction enzymes, buffers (relevant to the enzymes used) and DNA (plasmid or PCR product).

### 4.12.9 Gel visualisation

Once digestion completes, it is common to run the entire product on a gel[96], as explained (Section 4.12.7), allowing it to be visualised. When using plasmids, gel visualisation provided a method to confirm the size (in base pairs) of the digested DNA fragments and to excise fragments for further use (if excising, it is advisable to load a small amount of the product into an adjacent well for documentation). The gel was visualised using a Darkreader or a low-damaging UV light (Illustration 14).

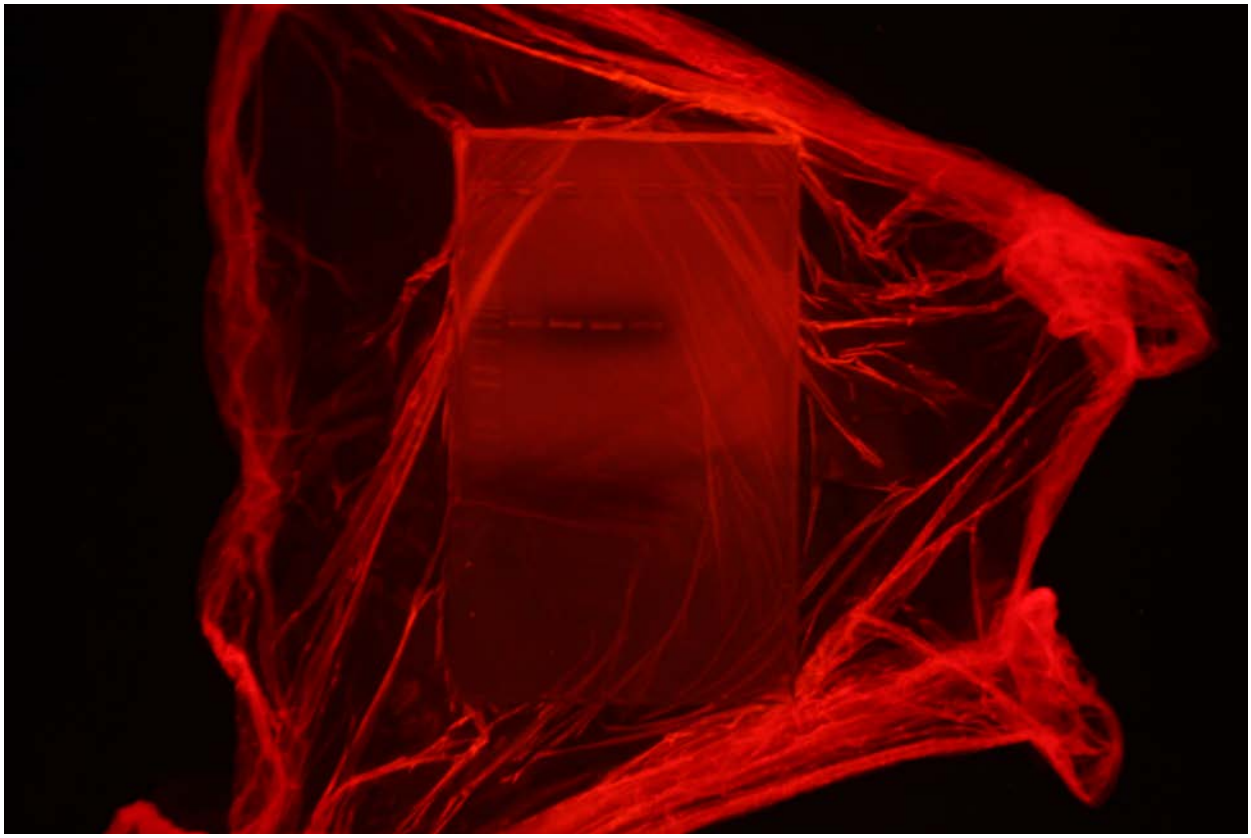

Illustration 14: Agarose gel on a Darkreader (illuminated by blue light polarised transilluminator and seen through polarised orange filter) showing from left to right DNA ladder and four subsequent DNA products of the same size. The gel shown was overlaid by cling film for support as it contains the carcinogenic compound Ethidium Bromide. Photo: Howard Boland.

### 4.12.10 Excising gel DNA fragments

If the desired product is visible (to the naked eye) the band can be excised from the gel using a sterile scalpel (Illustration 15). A scalpel was used to cut tightly around the gel band and transferred to a tube for storage or purification.

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[96] An alternative method is the use of heat inactivation, which stops enzymatic reaction by raising the temperature to around 60-80ºC for 10-20 minutes (Appendix XII.VI). By opting for this step it is possible to proceed directly to ligation, however this reduces checkpoints.

Illustration 15: Excising DNA from gel using scalpel. Teaching student as part of the work *Bacterial Light Sensor* (Section 5.10). In the example shown a (non-UV) Darkreader (Section 4.16.4) was used rather than a UV-transilluminator. Photo: Howard Boland.

4.12.11 Gel purification

To recover DNA from an excised gel band, a commercial kit (i.e. QIAgen gel purification kit) was used to purify (Appendix X). The gel band was first melted in a solution using a water bath, and precipitated using alcohol before binding the DNA to a filter, washing and eluting it in water, in similar steps to those used for plasmid purification (mini-prep) (Section 4.12.6).

4.12.12 Gel check

As with previous steps (Section 4.12.7), running a gel with a small amount of DNA provided a useful checkpoint after purification to ensure that material was still present and consistent with expected sizes.

4.12.13 Ligation

The final step in the molecular assembly process is ligation (Appendix XIII). Like digestion this used enzymes much in the opposite way, instead of cutting specific sequences of DNA, ligase repaired compatible ends of DNA. The process reconstituted a circular plasmid containing a

desired insert. In the process, two pieces of DNA, a backbone and an insert were added in a 1:7 ratio with ligase enzymes and a buffer solution.

4.12.14 Iteration

To complete the circle, the assembled or ligated construct was transformed into bacteria as described in section 4.12.1. Following these steps iteratively, it is possible to develop constructs of increasing complexity. As noted, this is a slow process and recent methods have emerged to overcome this.

4.12.15 Colony dilution

It is possible to generate DNA material using polymerase chain reaction. The process used a DNA template (e.g. from a colony) and amplified large amount of specific products (Appendix XI). It was also used to check if a colony contained a specific product (i.e. colony screening). Colonies were used directly by diluting (1:10) in water. Alternatively, it was possible to amplify DNA products from purified plasmids.

4.12.16 Polymerase chain reaction

Polymerase chain reaction or PCR is a reaction used to generate large amounts of a specific DNA product using primers. The method involved a two-step procedure that (1) sets up the reaction and (2) provided temperature conditions through a series of cyclical steps. Polymerase was used to transcribe or copy DNA. The primers worked with polymerase to bind and copy DNA at specific locations. The process of generating an increasing amount of this material is known as amplification. As more material of the target products become available, these form templates leading to exponential increase in copying speed (i.e. chain reaction). To apply conditions, a thermal cycling machine was used, since this can be programmed to rapidly change temperatures through a series of steps (i.e. initial, denature, annealing, etc.). A successful PCR provided a linear product that could be readily seen on a gel, and subsequent steps (Section 4.12.7 - 4.12.13) allowed the product to be used in the assembly processes.

4.12.17 Debugging

An important aspect in working with multi-step purification is loss of material. For instance, running DNA on a gel and purifying incurs a loss of material of about 10-20%, thus it was desirable to skip steps when possible. However, less iteration meant less evidence and fewer checkpoints.

4.12.18 Quantification

Quantification of DNA used sensitive laser-based spectrometer, known as a Nanodrop machine, capable of accurate readings of small quantities of DNA (Appendix XVIII). A small drop (1 μl) of DNA was suspended and using computer software a reading could be taken. This provided information about purity and quantity of DNA.

4.12.19 Sequencing

Sequencing was the final step providing accurate information about DNA samples (Appendix XX). In this research, an external institution (i.e. Wolfson Institute, UCL) performed the sequencing based on sending prepared and quantified DNA samples along with primers and paperwork stipulating conditions (i.e. annealing temperature).

## 4.13 DNA Tinkering: Taking it apart and putting it back together

To gain competency in manipulating genetic material, a period was spent learning the basics of recombinant technology through cloning and re-assembling DNA (Section 4.12). Starting out with a limited set of materials, the research employed a learning method known as tinkering that involves taking an existing artefact apart in order to put it back together (Lamancusa et al., 1996). For instance, the only plasmid available to me at the time had the quality of always (or constitutively) expressing GFP when transformed into *E. coli* (Section 4.12.1). Thus, to explore these methods it involved (1) digesting the plasmid to remove the section responsible for generating GFP, (2) testing that GFP expression was no longer present and (3) reconstituting it by following methods (Section 4.12) to reintroduce expression of GFP (Figure 9).

As an independent endeavour, it was satisfactory when the material responded as expected since this was more often not the case. For instance, the process of digesting plasmids into fragments would not always complete leaving a few intact plasmids capable of generating colonies when no colonies were expected (see diagram Figure 9 after 'taking apart'). Discussions with colleagues suggested a built-in noise that needed to be filtered out either through repetition or selection.

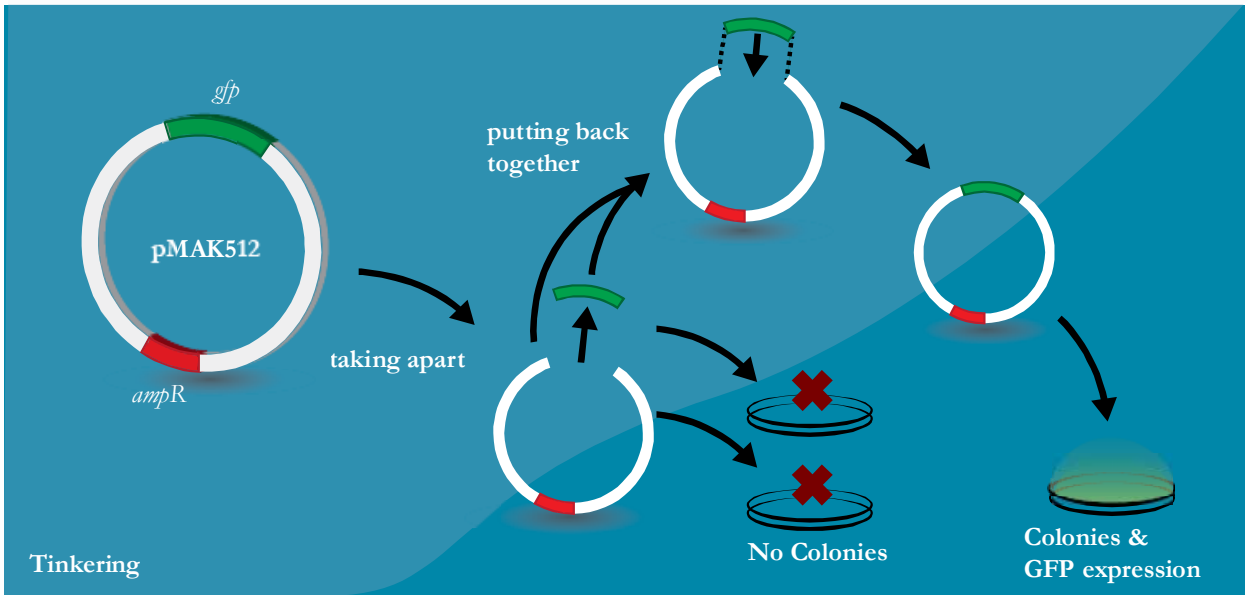


Figure 9: Initial experiments involved removing and reintroducing GFP from a genetic construct. Marked in red and annotated '*amp*R' is also an antibiotic cassette used to select only those bacteria containing the plasmid (i.e. positive selection). Shown in green and annotated '*gfp*' is the gene expressing GFP. The final construct expressed GFP and could be seen in individual cells using a microscope. Illustration: Howard Boland.

The idea of 'debugging' the system meant scrutinising every aspect of the experiment (Section 4.8) and then having to start all over. While mistakes are more common amongst inexperienced practitioners or reactions not being optimised, there remains an inherent statistical noise (being living) in the system that is understood through experience rather than clear guidelines thus evidence-base methods should also take into account this aspect.

## 4.14 Synthetic biology of standardisation and BioBricks™

Synthetic biology is a fast moving field that introduces both new methods and materials to (recombinant) molecular biology. The common practice for most laboratories today is still to assemble DNA using 'non-standardised' methods and by acquiring material through other processes. However, while learning molecular biology, in general, informs synthetic biology specifics, the influence of engineering approaches and the use of standardised parts cannot fully be appreciated by such (molecular biology) engagements alone. Thus, recombinant methods (Section 4.12), a central part of the scientific practice, became extended in the second year of the research to include synthetic biology specifics. Aimed at overcoming challenges of material access, steps had to be taken to facilitate this transition. For instance no work involving synthetic biology using BioBricks™ had previously been undertaken at my University and material access necessitated registration with the library of standardised parts. So, while the first period suggested using tutorials from synthetic biology (Section 4.6), these needed modification to

accommodate for material discrepancies. Despite this, many of the methods and working procedures overlap, however, there are significant differences and it is useful to briefly outline what synthetic biology involves in terms of materials and methods.

Within (molecular) synthetic biology, three major strands exists: minimal genome (Glass et al., 2006) attempting to minimise (genetic) components needed to sustain life; orthogonal ribosome (An and Chin, 2009) expanding protein encoding systems to create new material possibilities; and 'standardised parts', where this research is situated, is aimed at developing standardisation practices and methods to allow genetic manipulation and materials to be more accessible (Endy, 2005).

### 4.14.1 Library of BioBricks™

Standardisation using BioBricks™ can be understood as a methodology but includes material-specific elements through a library of genetic parts. Since around 2004, the number of available parts have increased from about 100 to around 7100 (partsregistry.org, 2012). A range of parts has been generated, including basic parts (e.g. genes, promoters, ribosome binding sites and terminators) and devices (e.g. reporters, receivers and senders) that are composites of individual parts providing more complex behaviour. Like recombinant methods (Section 4.12), the idea of a standard was conceptualised using enzymatic assembly methods and is understood through enzymatic definitions of carrying specific sites at the prefix and suffix of a genetic part. A 'part' or BioBrick™ is a characterised genetic component commonly submitted by students taking part in the iGEM competition or by professional researchers who contribute to the field. The BioBrick™ Foundation aims to build an open source platform that provides material access to its community members. A selection of parts is made available, consisting of several physical plates (96-well plates) containing multiple parts in the form of dried DNA (Illustration 16). An online database, partsregistry.org, contains key information (e.g. sequence, experience, characteristics) for each part. The library offers physical access to parts but its broader aims are to use parts to assemble or composite other parts through a method known as idempotent assembly.

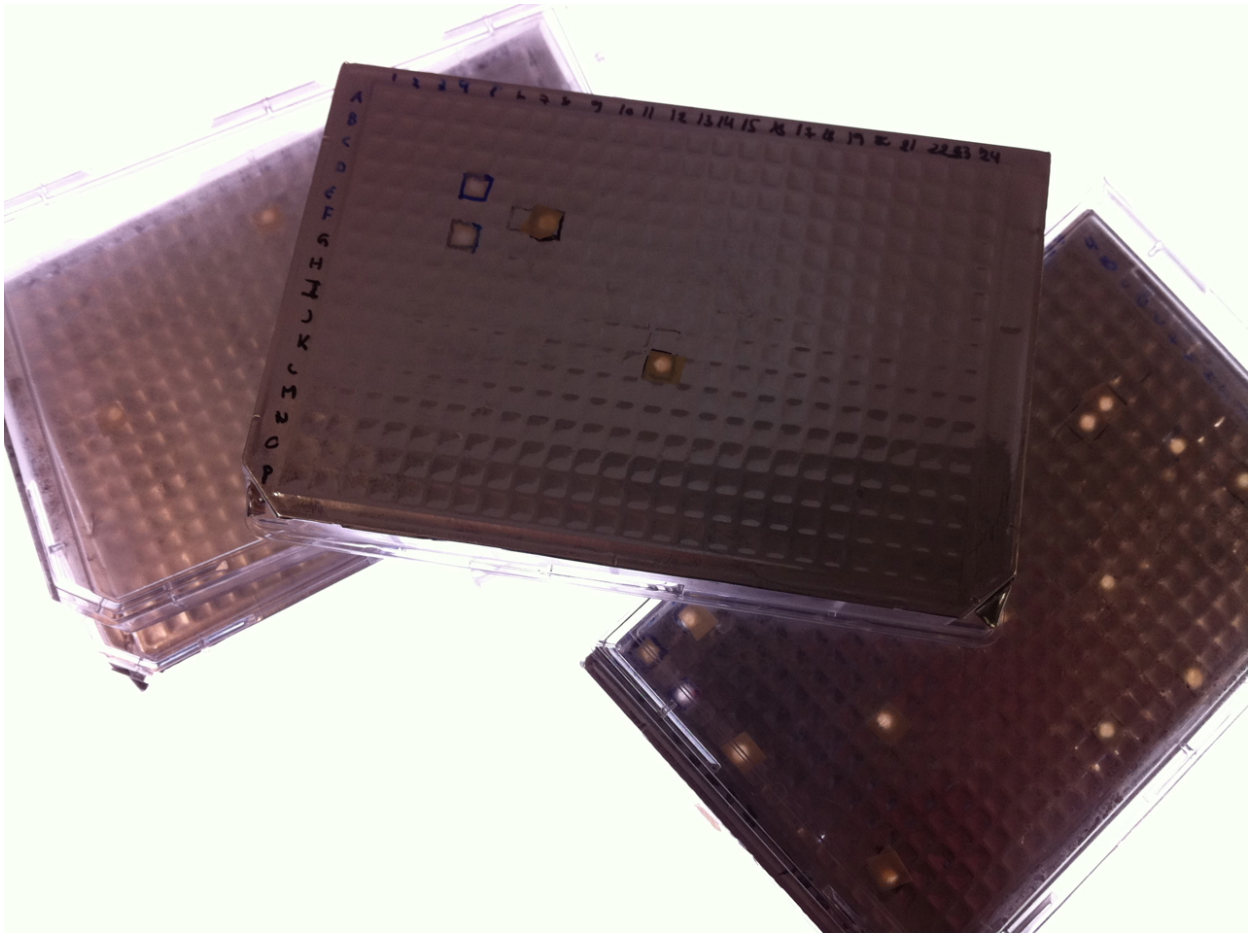

Illustration 16: Image of well plate. The library is distributed annually or upon request, and the DNA (plasmid) is rehydrated by adding nuclease free water and followed by transformation of plasmids into bacterial cells (described in section 4.12.1). Photo: Howard Boland.

### 4.14.2 Idempotent assembly

The concept of a standard describes how genetic parts conform to a set of rules aimed at simplifying the assembly of existing parts. As will be described, the rule is defined by exclusion of specific sequences and by having a prefix and suffix sequence (recognised enzymatic sites) that can be digested by a pre-defined set of enzymes (Appendix XII.I). Several standards exist (e.g. RFC-10, RFC-20) and there has yet to be consensus of a single standard. Different standards address specific requirements (e.g. generating scars or being scarless), and exploring standards continues to be a foundational research agenda in the field (iGEM headquarter, 2009). This research conformed to the most common of the BioBricks™ standards, know as RFC-10 developed by Knight (MIT, 2007). The diagram below (Figure 10) outlines how the standard was used to assemble new composite parts adhering to the same standard.

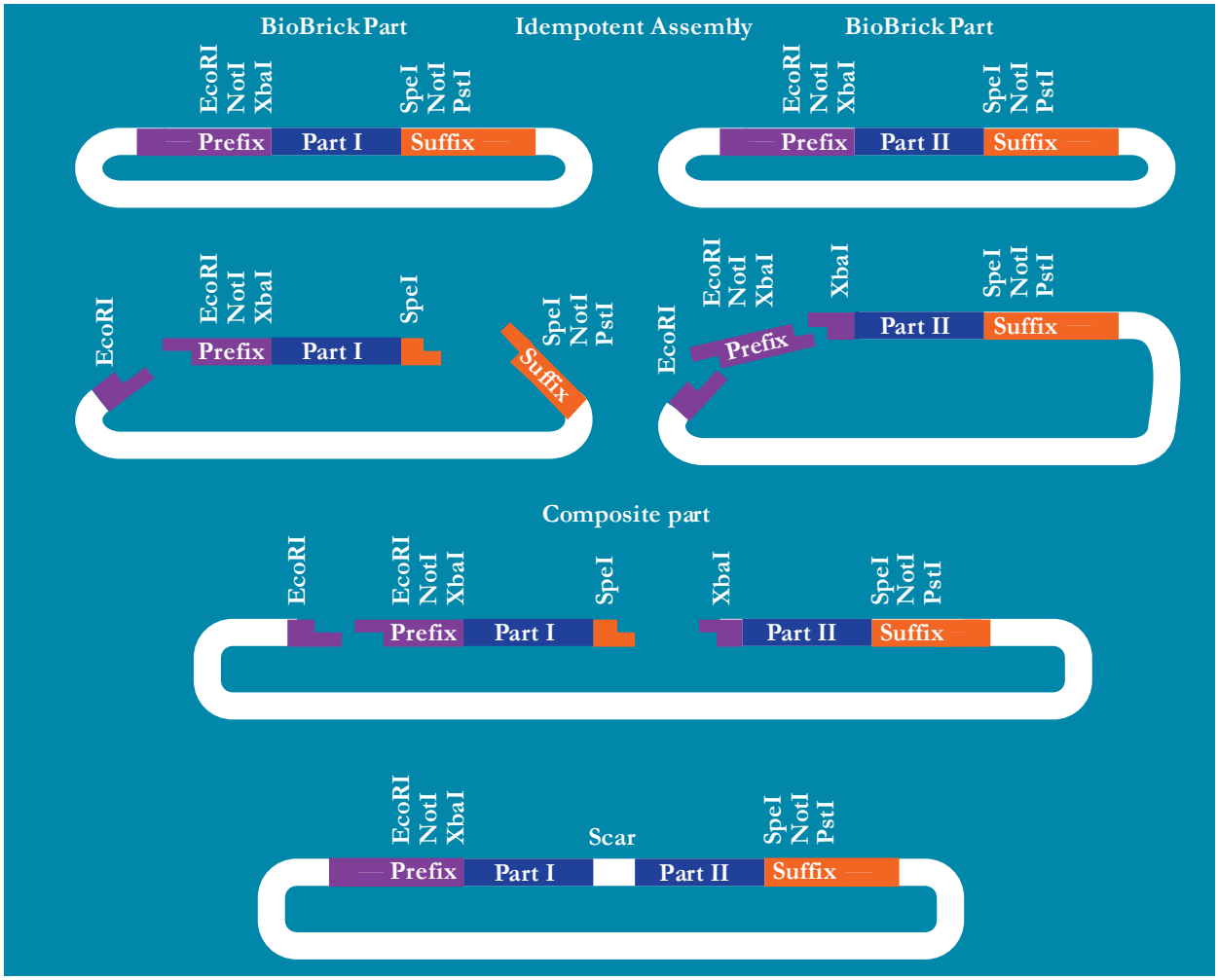


Figure 10: Idempotent assembly, showing two parts cut and assembled into a composite adhering to the same standard (e.g. containing the same flanking enzymes around the composite). The above standard uses RFC-10. Illustration: Howard Boland.

In idempotent assembly (following RFC-10), a part is flanked by a prefix (i.e. EcoRI, NotI and XbaI) and a suffix (i.e. SpeI, NotI and PstI). For the purpose of simplicity, the NotI site can be ignored as it played no role in the assembly process and a recent standardisation proposal has recommended that parts can be designed without this 'buffer' (MIT, 2010). As an enzymatic standard it rests on the capability of two specific restriction sites (i.e. XbaI and SpeI) to form compatible overhangs that can join and generate a sequence (known as a scar), no longer cleavable by either restriction enzymes. As shown in the above diagram (Figure 10), it is the production of a scar that reconstitutes the standard when compositing parts[97]. Further, in assembling multiple parts, positioning of parts in relation to each other (either upstream or downstream) can be achieved using restriction enzymes (e.g. cutting a part with EcoRI and SpeI yield an upstream part, while XbaI and PstI produces a downstream part).

[97] Idempotent design is also as a 'design pattern' within computer programming and has been widely used in designing service operations codes.

Assembling using standard parts (such as RFC-10) can simplify steps described in section 4.12. For instance, using what is known as a three-way ligation (or 3A-assembly, Appendix XIII.II) outlined in the diagram below (Figure 11). The principle of digestion follows the described idempotent method but removes the need for gel purification steps (by heating activating enzymes, Appendix XII.VI). To overcome a potential issue of self-ligation (i.e. digested plasmids circularising without taking up inserts) an additional linearised backbone (cut with EcoRI and PstI) was used as a host for two inserted parts. The linearised backbone contained a different antibiotic cassette to the backbones hosting the insert ensuring specific selection when transformed on selective media. Further, in using standardised backbones, these have been specifically designed to enable PCR amplification of parts (either existing or composited using described methods) using standard primers (i.e. VF2 and VR). This removed the need for growing parts in broth and purification of plasmids (Section 4.12.4 - 4.12.6) and enabled a standard method of verifying ligation

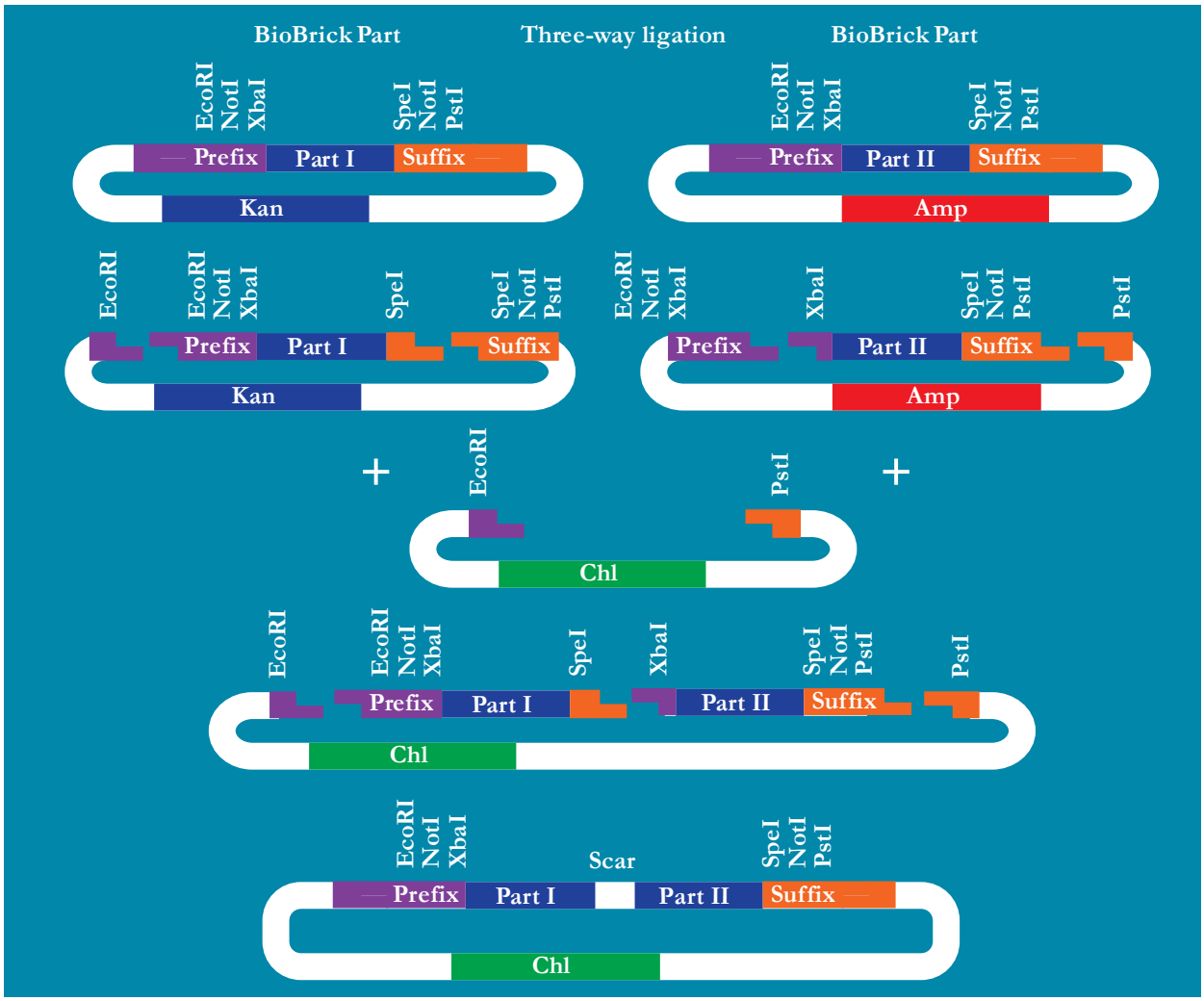


Figure 11: Three-way ligation. A host backbone with a different antibiotic cassette can be used to avoid time-consuming gel purification steps, and ease assembly of small parts. Illustration: Howard Boland.

### 4.14.3 Standardisation and its future

It is worth noting that the removal of gel purification was thought to overcome a major obstacle in robotic automatisation, a future aim for standardisation. As mentioned, the field has made significant progress during the course of this research and it is becoming increasingly questionable if adherence to a standard using restriction enzymes is redundant. New methods suggest reducing the number of assembly steps to a single PCR reaction involving multiple parts rather than the traditional two-component system and using linking sequences instead of restriction enzymes (Section 4.12). With rapid technological advances it seems likely that current standards will be left behind, in particular since this often requires mutation of sequences to ensure adherence. As new methods become the currency of synthetic biology, the value of the library is likely to shift towards parts being well-characterised rather than pertaining to a specific standard.

## 4.15 Methods in microbiology

Synthetic and molecular biology were the core scientific undertaking of the research. Most of the work was done using bacterial systems, mainly through various laboratory strains of *E. coli*. Some methods were used to assay and set-up systems or displays. However, the research also explored other microbial systems and their capabilities. These included preparation of media, exploration of growth and behaviour such as swarming, and looking at potentials in biodegradation of dyes and magnetism in bacteria and finally the use of fermentation techniques.

### 4.15.1 Strains and types

As mentioned, most work involved *E. coli* strains (i.e. XL-1 Blue, DH5-alpha, Mach-1, MG1655). These were prepared as competent cells and used to transform bacteria (Section 4.12.1) as part of the aforementioned recombinant and synthetic methods. In some cases, specialised knockout strains of *E. coli* with disrupted genomic expressions were obtained and used in combination with plasmids to enhance a particular expression. For instance, an indole inefficient or odourless strain (e.g. YYC-912) was used in *Banana Bacteria* (Section 5.8), and two osmolarlity inefficient strains (e.g. RU-1012, JT-2) were used in *Bacteria Light Sensor* (Section 5.10). In *Transient Images* (Section 5.14) a consortium of sewage bacteria (mainly *Clostridium*) and *Shewanella* were used, as these are capable of degrading textile azo-dyes. Attempts were made to grow *Magnetospirillium gryphiswaldense*, a magnetotactic wild-type bacteria for the proposed work *Living Mirror* (Section

5.11). Apart from *E. coli*, these latter species require both specialised media and anaerobic or microaerophilic (low-oxygen) growing conditions.

### 4.15.2 Media and growth

Most of the media prepared were broths and agar plates (i.e. Lysogenic agar) used to grow *E. coli*. All media were autoclaved prior to use and prepared under sterile conditions using antiseptic techniques by working close to flames, applying sterile tips and minimising exposure surfaces. In special cases, use of syringes, microfilters and ethanol were used to ensure sterile conditions (e.g. working with slow growing organisms such as *M. gryphiswaldense*).

Experimental approaches to investigate swarming used agar with varying water content from viscous or soft agar to hard. Hard and soft agar were also, in some cases, layered on plates. Chemotaxis (i.e. cells' ability of directing their movement either to or from a chemical substance, e.g. a sugar) was explored by incorporating agar plates with sugar in the form of liquid droplets or by embedding sugar rich agar into normal agar (Section 5.4 - 5.5).

When working with bacteria containing plasmids, selective antibiotics were supplied to ensure conservation. Only bacteria containing plasmids survive as the plasmid promotes production of enzymes capable of breaking down antibiotics. In some cases, chemical substances were added either to promote the production of proteins or used as a substrate that enzymes convert into some other compound.

Specialised media to grow esoteric strains and hardy bacteria were prepared as separate components and mixed upon use. For instance, to prepare minimal media, this involved preparing amino acids, vitamin solution, carbon source (e.g. a sugar derivate) and a base media (Illustration 17). Anaerobic conditions were prepared by purging media with nitrogen gas.


Illustration 17: Preparing semi-defined media for use in *Transient Images*. Photo: Howard Boland.

### 4.15.3 Fermentation

Fermentation was explored as part of the work *Stress-o-stat* (Section 5.7) and took place in a specialised laboratory. The set-up allowed a great deal of control over growth and is normally used to achieve large volumes to harvest a particular product (e.g. a polymer or a protein). A fermenter containing a spage stirrer, a cooling system and multiple ports was used. Several sensors were connected (e.g. thermometer, oxygen probe and pH-probe) and the conditions inside adjusted automatically or manually by taking readings at intervals (Illustration 18). A modular control unit provided reading and control of parameters.

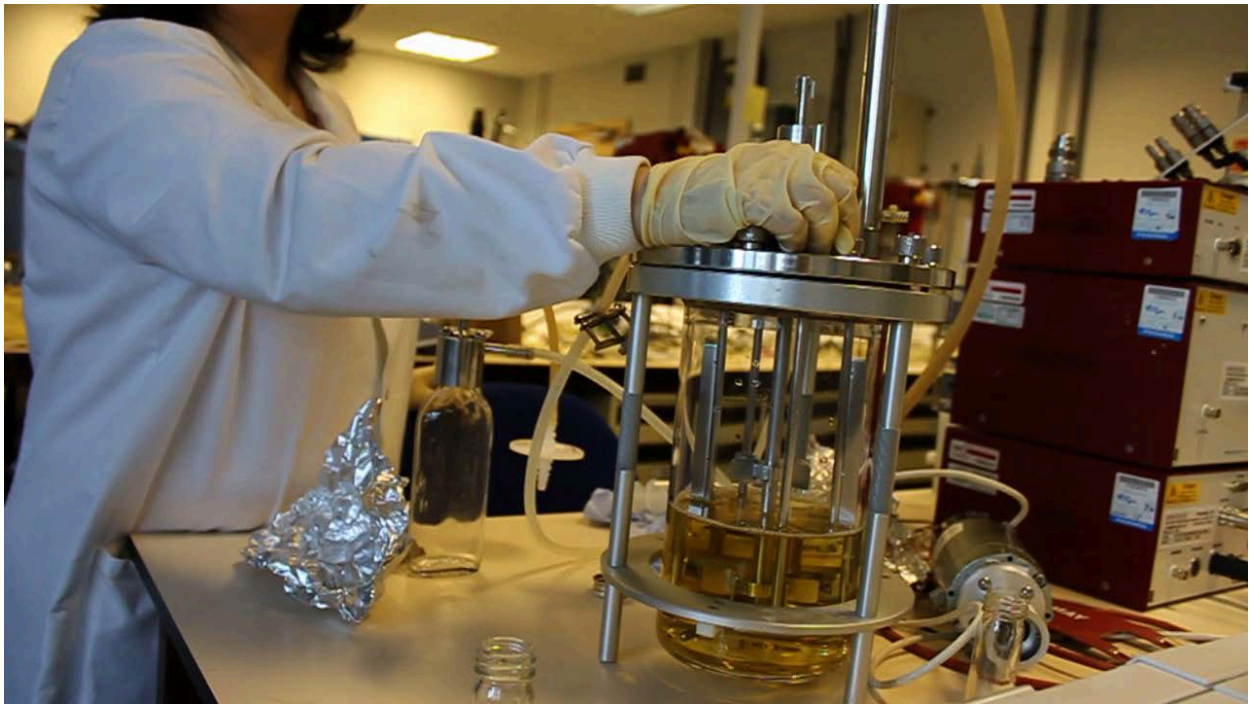

Illustration 18: Setting up a fermenter. The fermentation unit consists of several ports allowing measurements and liquids to be added. A control unit is used to take readings (e.g. oxygen level) and alter parameters (e.g. stirring speed). Photo: Howard Boland.

The system is open to inventive adjustment and was, in this research, extended to generate continuous growth by a set-up known as a chemostat.

A chemostat is a liquid fermentation set-up that can maintain a constant cell population using a three-tier system, a feed, a fermenter and a deposit connected via tubes and pumps (Illustration 19).

Illustration 19: Chemostat set-up, three-tier system with feed (left), fermenter (centre), and deposit (left). Photo: Howard Boland.

4.15.4 Fungi activities

A few additional activities included growing a fungi (*Pleutrois)* using dextrose broth (Illustration 20) and also using a semi-solid solution by adding sawdust with the aim of generating fruiting bodies or mushrooms. The capability of bioremediation in fungi was proposed as an additional system to extend art potentials in *Transient Images* (Section 5.14).


Illustration 20: Fungal activities included growing *Pleutrois* with the aim of using this organism in bioremediation (i.e. detoxify aromatic amines). Photo: Howard Boland.

## 4.16 Documentation

While it has been argued that an important aspect of exhibiting bio art is the presence of the living, most biological processes and experiments have a limited life span, and the process of recording, thus, becomes important. As already discussed (Section 4.12), documentation plays a particular role when working with invisible compounds within liquids. Checkpoints that gather evidence are critical in evidence-based processes both as data and for the purposes of layering. For instance, in assembling DNA the use of agarose gels and UV-documentation systems provided data about sizes and suggested if these could be used in subsequent steps.

Scientific procedures and data commonly rely on quantification or extrapolation of numerical values. These were useful guiding points in ensuring quality and repeatability. As discussed in the first section of the chapter, machine readouts providing numerical data is of particular use to the

sciences since the data generated is the outcome, however, for this research the data was subservient to the materials and not the other way around (unless this was seen as the same).

### 4.16.1 Scientific instruments and gels

The iterative processes described in section 4.12 commonly generated gel photographs. These photos serve as important documentation when assembling DNA and can be used as data in scientific papers. Gels were used in this research to verify outcomes but have not served any specific role in artistic outcomes. They form part of the evidence-based processes. Similarly, instruments such as spectrometers used to measure cell density and in quantification processes of DNA were used in the preparation of materials.

### 4.16.2 Observation, photography, time-lapse and video

Given the size of bacteria and slowness of growth and expression, observation played an important role. Techniques such as microscopy, time-lapse and use of Darkreader provided access to multiple perspectives including size, time and expression (Illustration 21). Photography or drawings were frequently used as documentation. Photography was an ongoing activity used in both learning, observation and as final documentation (e.g. outcomes). Bringing a camera into the laboratory space as a documentation tool is less common in the sciences and consequently brought about reactions. As a recording tool it can also be seen as invasive and it takes time to overcome and establish a natural way of using it. The purpose of photography was not to capture the scientists in the laboratory, as these were not the subjects of the research, rather it was to capture images of processes, material and outcomes.

The study began by exploring growth and therefore quickly identified time-lapse as a useful technique to be incorporated as a documentation method. Since no pre-existing time-lapse facility existed, this needed to be set-up. In particular, exploration of growth on plates used shared equipment such as an incubator and setting up facilities could interfere with other experiments. To overcoming these, a *Growth Chamber* (Section 5.13) was developed consisting of a wooden cabinet with a transilluminator to enable time-lapse.


Illustration 21: Laboratory bench with early set-up using time-lapse. Photo: Howard Boland.

Like photography, videos were made to record observations and towards final documentation. For instance, time-lapse sequences were composited into single clips (using Apple QuickTime 7). Video compositing to provide documentation of overall projects was done using Adobe Premiere CS5 and Adobe After Effects CS5.

### 4.16.3 Microscopy

Microscopy studies served multiple roles. A fluorescent microscope with a camera adapter was used to record and visualise individual cells and expression (e.g. GFP). As a research tool it also served to check viability and contamination of a culture. This was done using staining techniques (e.g. Gram staining or Propidium Iodide staining) or by looking at individual cells, since it is possible to observe swimming patterns in many of these organisms (Illustration 22).

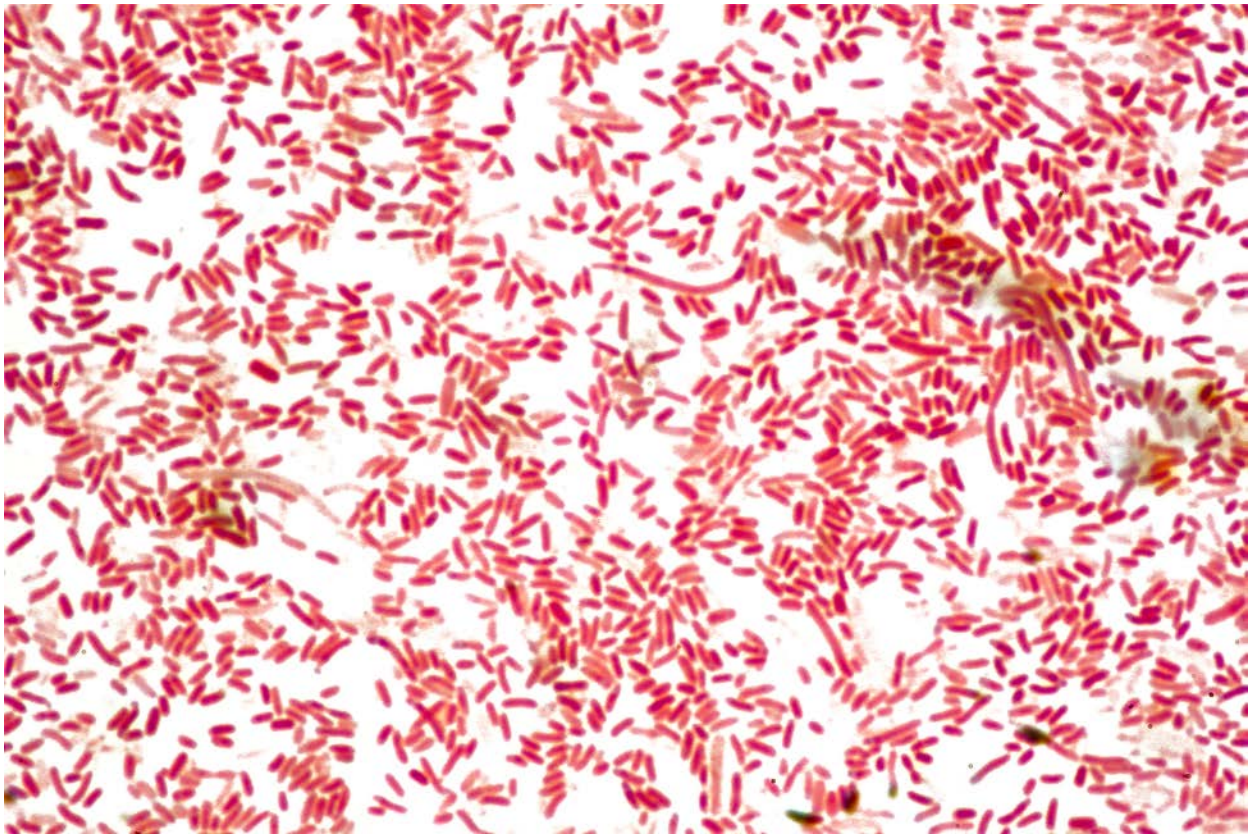

Illustration 22: Gram staining, *E. coli* (DH5-alpha). Photo: Howard Boland.

### 4.16.4 Darkreader

During the course of the research, our laboratory procured a Darkreader for cutting DNA from agarose gel (Section 4.12.9-4.12.10). As a visualising tool, its principle design is based on a transilluminator but uses blue lights with a diffusion filter below a polarised blue filter and an external polarised orange filter. Placing a fluorescing source on the blue filter and viewing it through the orange filter, blocks the blue light bringing the light from the fluorescent green (in the case of GFP) into a distinct and clear view (Illustration 23).

A literature search suggested similar systems have been implemented in *The Eighth Day* (Kac, 2001) and a real-time gel visualiser[98] (Jankowski et al., 2009). The Darkreader (developed by Clare Chemical Research), used in this research, is a patented solution (Seville, 2005) and as such its report discloses all information from construction to procuring its components. The aim was to add a similar feature to the *Growth Chamber* (Section 5.13) using filters and lights.

[98] For example, Owl B2 EasyCast Gel Box from Pearl Biotech LLC.

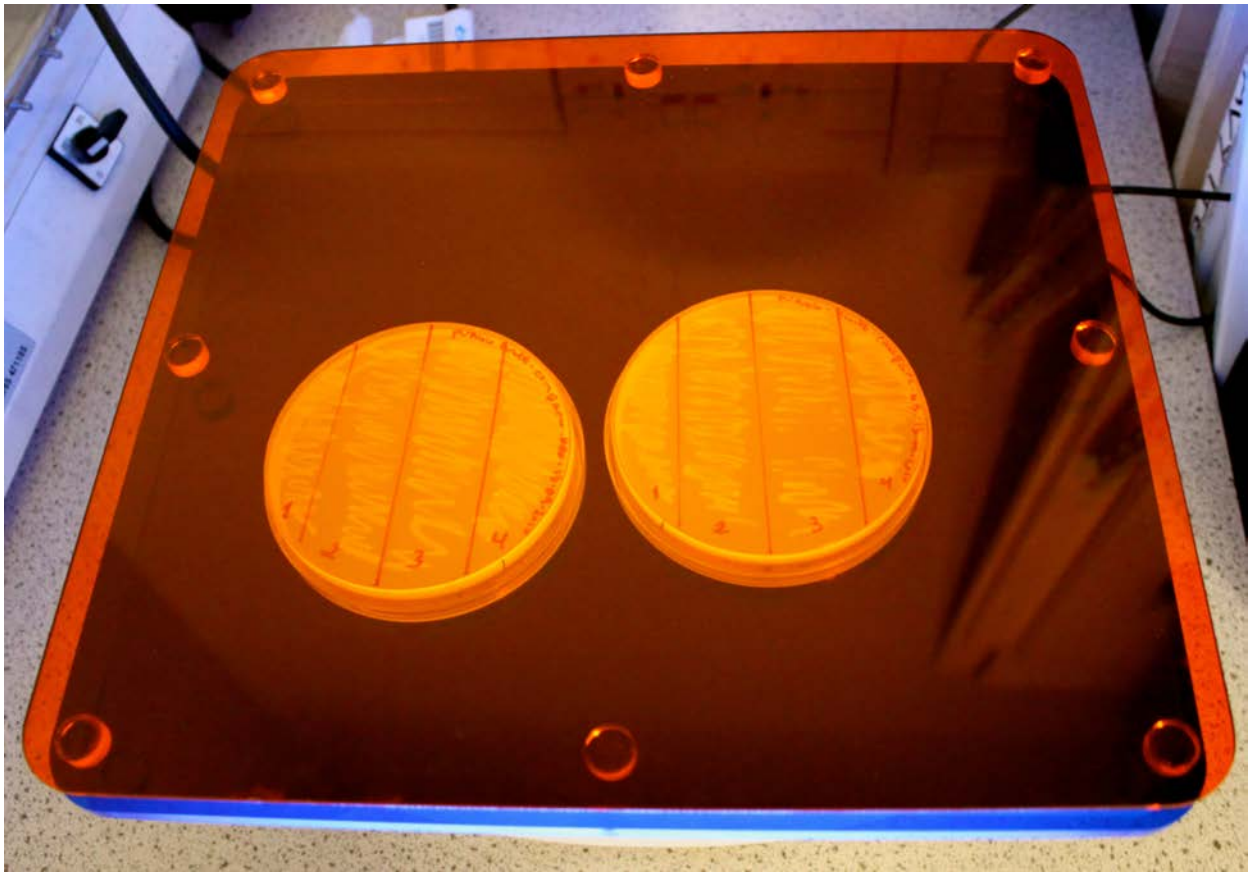

Illustration 23: Darkreader (Clare Chemical Research). Photo: Howard Boland.

### 4.16.5 Laboratory book

The daily practice with ongoing experiments often repeated several times creates the need to keep records. Returning to the previous point of invisible compounds, working with molecular biology is often outside our senses. Immersed in these settings, the practitioner must retain the same focus and scrutiny as scientific peers. To keep track of material and experiments, a simple diary was used, noting quantity of chemical and mixtures for each experiment in order to enable back track during iterations.

No formal laboratory report book was used as it was not clear at the beginning what level of immersion the research entailed and further it was unclear what purpose such book would serve in a scientific context. It is recommended that training in using such books would be useful for the art practitioner. The use of notebooks changed over time. In the first period, this was done as a reflective diary and was concerned with the cultural clash. In the learning phase, a series of drawings were used to imagine experiments. This was replaced by a notebook outlining specific experiments and included drawings of how these were done (Illustration 24).

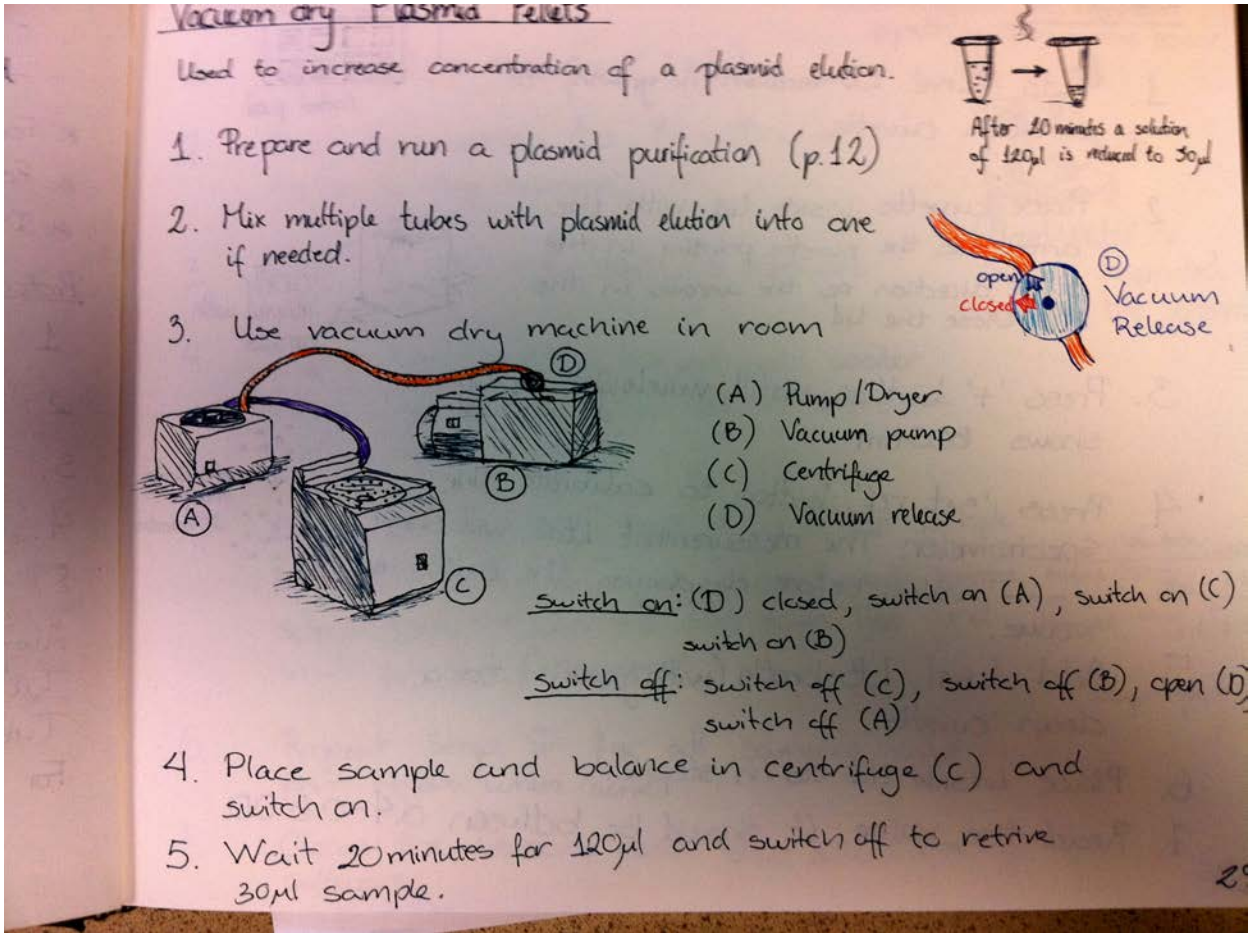


Illustration 24: Page sample from laboratory book used to outline specific protocols. Photo: Howard Boland.

During iterative processes, where experiments were repeated, this used a notebook with short annotations and a wiki through the online platform (openwetware.org) allowing gel pictures and other recordings to be organised by date. The notebooks were active research tools and were used to modify and repeat experiments based on outcomes.

### 4.16.6 Reflection

As a practice, evaluation and reflection were ongoing processes. Reflective methods guided the research as a whole and were instrumental in decision-making processes. These methods aim to unpack concepts and questions that emerged as the practice developed through stages. Laboratory and studio work were documented using a diary enabling reflective analysis of ongoing practice. As discussed, notebooks changed format over time but were active research tools. Since the research involved an immersive practice with multiple experiments, there were long stages of deep scientific engagements involving wet work, documentation and daily evaluation followed by outcomes and periods of reflection. These can be thought of as iterative

and cyclical processes. Reflective practices, particularly when going through material struggles, were central in opening new material potentials.

### 4.17 Evidence-based art practice

This research took place in a laboratory setting, using material, methods, conditions and instruments in the evidence gathering process. Use of scientific evidence approaches aimed to stake claims about materials by building a layered process scrutinised in an iterative manner by taking measurements and making observations. Artistic outcomes and experimentations rely on scientific evidence processes to corroborate data through a series of trusted 'inscription devices"[99] (Latour and Woolgar, 1986: 51). Evidence-based practices have alignments with medical practices (e.g. evidence-based medicine) that place importance on "tightening up scientific documentation" in order to make decisions based on the best evidence available (Hjørland, 2011: 1301). As a way of doing research, its criticism lies in moving towards standardisation and mechanised processes that tend to ignore social and historical contexts impacting upon decisions and it suffers from weaknesses found in empiricism (Hjørland, 2011: 1301-1309). Applied to bio art and this research or what we may call an evidence-based art practices (EBAP), this research relies on gathering data to support the construction process both for itself and in the type of knowledge narrative it unfolds. EBAP comes as a result of the type of material engagement and in the case of this research an immersion with specific scientific practices.

EBAP may be more broadly said to involve processes of experimentation that guides the material through a layering process involving documentation and production of material in an increasing complexity, where each step is scrutinised through an iterative process that corroborates sufficient evidence.

Evidence-based approaches involved immersion into scientific practices with iterations around methods or procedures of documentation, observation, detection, isolation and construction. The layering processes had to generate precise material, much of which is invisible or unobservable, through a series of steps in order to combine material into something more complex. Chemical interaction and specificity of these modes are non-trivial and iterative learning was needed to perform these, and further it used experience for optimisation.

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[99] Any standardised apparatus or configuration capable of transforming a material substance into a figure or diagram valid in the corroboration of evidence, and thus these play a significant role in the production of scientific literature.

### 4.18 Summary

The aim of the practice has been to extend the boundary conditions of art through an investigation of materials and methods within synthetic and molecular biology towards art production. Artists' access to laboratory spaces has often been limited and in order to undertake this study formal laboratory arrangements were needed. This involved a daily laboratory practice and situated the research within a scientific context. The cultural clash and steep knowledge curve experienced by an artist entering laboratory spaces provide clues to why many opt for collaboration. Indeed, the benefits of collaborations are far reaching but several issues are thrown up by such engagements in terms of ownership and division of work. On the other hand, bio artists have argued that the need for artists to learn scientific methods and adopt a hybrid skill set in order to take active ownership over artworks that often involve ethical dilemmas. To overcome challenges of knowledge (or language) thresholds and to establish independence in working with synthetic biology, an immersive laboratory practice was appropriate. As for long-standing methods of learning a second language, this places the practitioner in an intense learning environment. Approaches for learning computer programming were also useful since these often rely on producing structures from fragmented knowledge models. However, despite the central dogma of modern biology described as an informational flow of codes, these concepts emerge from different backgrounds (i.e. evolution) to computational understandings. Synthetic biology's alliance with engineering practices attempts to reconnect these fields by novel approaches of appropriating genetic affordances (e.g. tinkering, use of language).

The independent laboratory practice undertaken for the duration of this research also involved an overhead of generating generic scientific material, non-specific to artistic output, but gave a sense of ownership in terms of practice. Working with transparent liquids as a layering process cannot easily be guided by other practices or our senses, and the specific nature of the research necessitated a detailed understanding of biological components (e.g. promoter, genes). Materials were obtained from internal and external institutions that in some circumstances required legal agreements, making the process slow. Later, when working with synthetic biology many components were available through a distributed library of genetic parts.

Scientific papers and bioinformatics (i.e. analysis of genomic sequence data) played a central role in developing experiments. The laboratory work established a workflow that lent itself to molecular methods and later expanded into synthetic biology enabling access to a range of materials (library of parts) and methods (idempotent assembly) that were instrumental in generating outcomes. Using sequence information generated through material manipulation and

by comparing this with initial sequence data, it was possible to consolidate information and materials. With focus on bacteria, the practice was situated within microbiology and involved various strains of *E. coli*, growth media and natural organisms with capabilities such as degrading textile dyes. Understanding potentials in both natural organisms and GMOs enriched the practice by extending its ability to introduce predictable behaviour. For instance, the use of fermentation systems aimed at modulating genetic expressions by enabling more specific control.

To account for diverse research activities (e.g. evidence gathering, recording, protocols, reflection) documentation utilised a range of modalities (e.g. photography, video, drawing, notes, gels, graphs, etc.). While outcomes focus on presenting living matter, documentation provided mobility and additional insights by mediating biological processes often difficult to observe.

Thus, the use of the evidence-based methods was aimed at staking claims about material by gathering and documenting scientific-evidence for the purpose of decision-making. As an immersive laboratory practice combining scientific-evidence gathering with reflective processes and documentation, it developed a methodology for producing artworks using synthetic biology discussed in what follows (Chapter 5).

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# Chapter 5
# Experiments and outcomes

## 5.1 Introduction

This research embarked on an immersive practice that intimately engaged with scientific material and methods resulting in multiple outcomes. To date, artists' access to molecular laboratories has been limited to short periods (e.g. from weeks to a few months) as opposed to this research established over three years. As seen in the methodology (Chapter 4), the practice is a synthesis of transdisciplinary methods across art and science. An early question asked how artists might come to conceptualise an independent immersive laboratory practice. Thus, the preceding and current chapters contribute to an answer by offering a framework to how such practices may be undertaken.

While the previous chapter elaborated on the particular methodological approach (i.e. immersive laboratory practice), this chapter provides answers to key research questions by showing: (1) how art practitioners can engage with biological knowledge (i.e. recombinant and synthetic biology) on a more profound level towards art production and the challenges thrown up by such approaches and (2) how this research is contextualised within and how it differs from existing bio art practices by conceptualising outcomes and innovative approaches to broker understandings of non-human biological systems (e.g. bacteria).

Given the intensity of the practice, an overview will show how outcomes interrelate. Specific outcomes are subsequently discussed in further detail and structured chronologically and by relation (e.g. theme, material and methods). Many processes described were iterative, non-cumulative and they also include experiments that did not generate final results but open future scope for research.

## 5.2 Overview

Outcomes were interlinked through a variety of undertakings that built and negotiated an increasingly complex relationship with the material. Projects were developed towards clear experiential expressions and evaluated throughout by reflection. The initial period of laboratory practice involved observation of growth and exploration of behaviour and provided substantial groundwork to study genetic potentials. By consolidating methods and learning, an early

experiment *Bacterial World* (Section 5.3.1) suggested using bacteria as data to visualise population scenarios by drawing crude maps on a petri dish and considered alternative agar shapes (e.g. a sphere). Similarly, *Suspended Lights* (Section 5.3.2) contemplates agar architectures by using fluorescent bacteria grown on agar-covered strings to give an impression of growth suspended through space. Behavioural potentials were first examined through pattern-formation and swarming. Further, chemotaxis experiments (see also Section 4.15.2) used sugar enrichments leading to the display, *Sugar Rush* (Section 5.5) - a clock-like set-up of five sugars centred by *E. coli* to study attraction mechanisms. Documentation was done using photography, however, given the slowness of growth, a time-lapse facility *Growth Chamber* (Section 5.13) was later built to capture time-delayed events. To enable external investigation of internal phenomena, substantial efforts were made in learning molecular biology by looking at genetics. Borrowing from digital art practices, engineering and computer programming, learning methods using 'tinkering' (Section 4.13) were initially employed and involved taking genetic constructs apart and reassembling fragments on a molecular level. Through evidence-based experimentation, this research sought to tap into ways of visualising differences in growth and behaviour using genetics. A major study looked at genetic factors involved in stress response in the work *katE* (Section 5.6). This provided a complete framework of producing artworks using genetics and involved (1) design studies, (2) synthesising material, (3) laboratory work and (4) corroborating evidence. While the initial results did not fulfil desired aims, it highlighted clear differences between outcomes in the arts and sciences; and suggested methods to overcome these challenges (i.e. synthetic biology) towards artistic expressions. Through experimental and material struggles, the research returned to its initial goals of using synthetic biology and the major study was completed with the expression of fluorescence driven by stress factors and offered a way of tapping into invisible processes. The work was followed into a major artwork, *Stress-o-stat* (Section 5.7), where cell population could be controlled allowing stress parameters to be manipulated in a fermentation set-up called a chemostat. Initially, *katE* used a green reporter construct (i.e. GFP) and later a red reporting system (RFP – Section 5.6.10) was also created to analyse differences in expression of light and colour in various media. From these major developments several side-roads were discovered opening additional potentials. For instance, while testing BioBricks™ - an olfactory work was developed into *Banana Bacteria* (Section 5.8) using a genetic construct capable of generating banana-oil scent. An advanced oscillating light circuit was explored in *Tick Tock Bacteria* (Section 5.9). Discussions around behaviour also led the research into discovering magnetotactic bacteria that in spite of being particularly hard to grow was developed into a proposed artwork, *Living Mirror* (Section 5.11). As a two-phase project, it

attempted to use these bacteria to generate a mirror by manipulating the location of cells using a magnetic array. The difficulties in cultivating these cells led the directed attention to genetic solutions for the system; however, more research is needed for such a system to work. Instead, the experiment *Bacterial Compass* (Section 5.12) used magnetic nanoparticles to control bacteria behaviour and provided a method of interacting directly with cells. With successful expression of *katE*, a proposal, *Bacterial Light Sensor* (Section 5.10), was put forward to develop a more ambitious work that introduced light-sensing capabilities in *E. coli*. Expanding on material and previous efforts in synthetic biology this involved a significant period of genetic assembly. Although the potentials of controlling such a system is far reaching, more stability is needed for the system to be exchanged and worked on by the synthetic biology community. Finally, possibilities of using textile dyes (known as azo-dyes) to produce images were developed using sewage bacteria. Recordings used time-lapse (*Growth Chamber*, Section 5.13) and resulted in appearing and disappearing images, hence accordingly named *Transient Images* (Section 5.14). The work uses computational approaches to generate images by varying inoculum and also brought the practice into the realm of bioremediation and bio-systems.

### 5.3 Bacterial growth

Prior to engagements with molecular and synthetic biology, this research began by exploring growth as a process. On agar, the living status of bacteria[100] allows migration through growth and thus changing pattern formation. However, combining microbiology and art easily falls back into representation, raising the problem of using traditional (artistic) methods to address the post-biological (see Section 2.5.4). To further this argument, such outputs often ignore any biological significations and tend to focus on aesthetical, ethical or cultural significance. On the most basic level, outputs using biology to produce traditional representations (without incorporating life-processes or the specific material qualities of bio matter in the art making) tend to deal with surface-based understanding of pluralities addressed in bio art that should not simply be reduced to painting a 'pretty picture' (see Section 2.3). Rather, of interest were the numerous artists who have combined biological material and representation that establish deeper material connections (e.g. de Meneze' *Decon*, Kac's *Genesis*, Davis' *Microvenus*).

[100] In most cases when referring to bacteria – unless stated can be exemplified by *E. coli*.

### 5.3.1 *Bacteria World*

Early stages of the practice used the earth-like circular shape of petri dishes to create a standard projection map, in the experimental display *Bacterial World* (2010). A printout from NASA (Mayhew et al., 2007) showing the world at night with lights from cities and human habitation outlined the boundaries of land and 'civilisation'.

The printout was used as a template and city lights drawn by swabbing transformed *E. coli* (Section 4.12.1) expressing GFP[101] onto two plates containing ampicillin antibiotics (Section 4.15.2). Visible colonies were generated within 10 hours and continued to double every 20 minutes (Illustration 25).

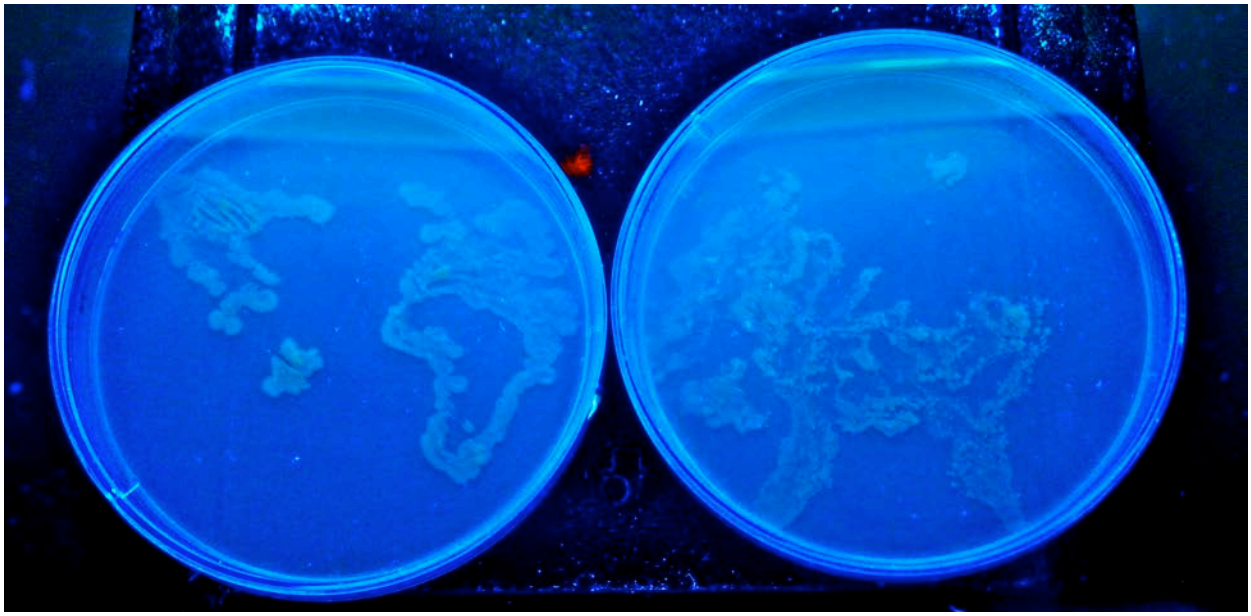

Illustration 25: *Bacterial World*, a projected map showing two continents outlined by bacteria on a petri dish after 3 days of growth. Photo: Howard Boland.

Growth in bacteria becomes an analogue to human and technological expansion, colonisation, resource scarcity and scientific agendas of "feeding an ever-growing population" (Section 2.2). Considering bacteria as data can open a speculation in population growth to simulate out-of-control growth and future scenarios. A more comprehensive artwork suggested building a spherical surface (Figure 12 & Illustration 26).

[101] Using the plasmid pMAK512 (provided by Anatolyi Markiv), constitutively expressing GFP.

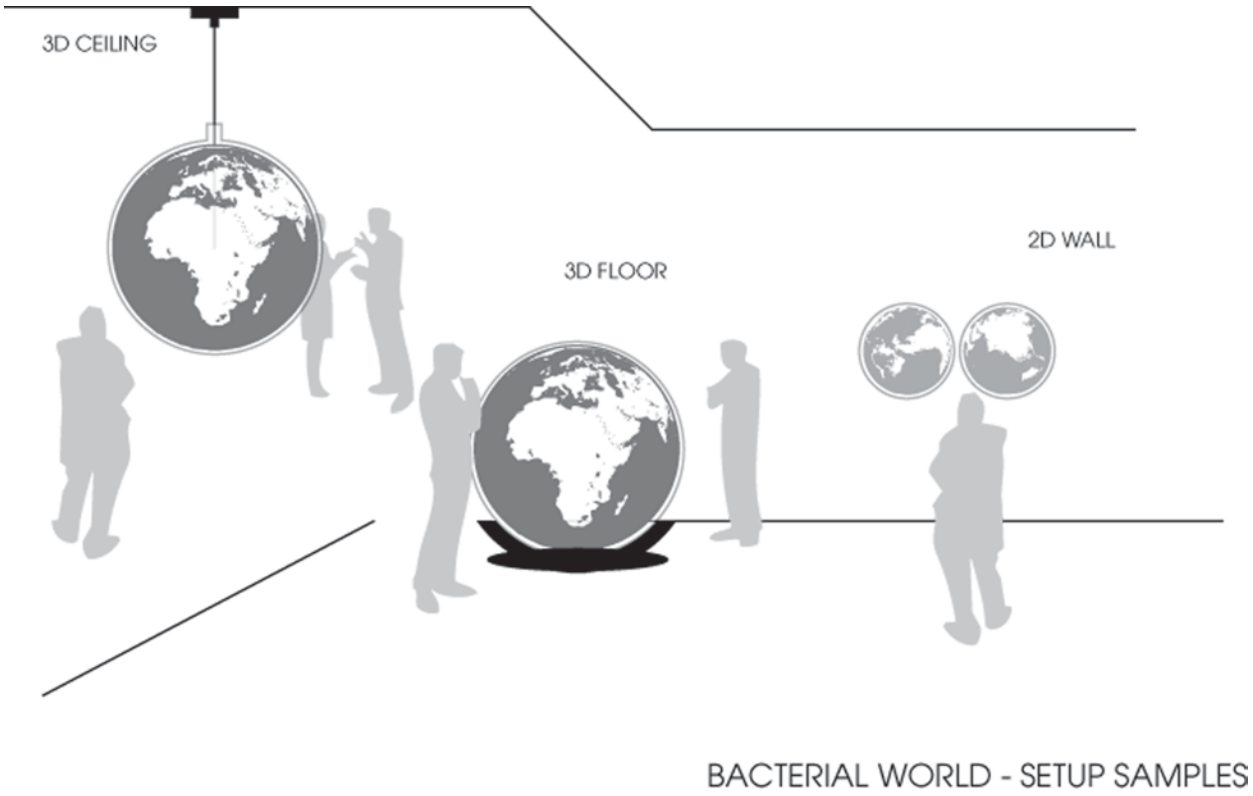


Figure 12: *Bacterial World* - 3D set-up, bridges ideas of expanding bacterial colonies with expanding colonisation of our world. Illustration: Howard Boland.

Several features could be added for creative realism. For instance, low concentration of various antibiotics generate arid terrains or mountains, reporter genes producing different colours visualise how cities grow and even merge, and dyes could outline sea and land. *E. coli*, also referred to as 'genetic workhorse' of the 21st century (Rudd, 2000; Zimmer, 2008), is routinely used in laboratories to serve scientific and social aims to alleviate human suffering and provide solutions to feed and maintain human population (Figure 2). Using the same organisms entrusted to alleviate burdens, we may paradoxically end up in the same 'out of control' scenario visualised in the work. *Bacterial World* considers what happens when colonies grow uncurbed and offers an imaginative living map of the world that is both multi-layered and incorporates a critical metaphorical futuristic reflection.

Illustration 26: Preparation of *Bacteria World* in acrylic plastic using a frozen balloon for hollow inside. Photo: Howard Boland.

### 5.3.2 *Suspended Lights*

Growth was a central part of experimentation and explored throughout the research. *Suspended Lights* suggests creating an architectural or sculptural suspension by growing fluorescent bacteria on agar-coated strings. It shares with *Stress-o-stat* (Section 5.7) a way of spatially displacing bacteria. To generate suspended traces of light, it was desirable for strings to be thin in order to merge with the background. While the work is processes-based through growth, time-lapse offered a sense of motion.

Various strings (e.g. mylar threads, fish wires, copper wires and cotton strings) were autoclaved and dipped in LB-agar with ampicillin antibiotics (Section 4.15.2) to provide a solid coat. Strings were then transferred to a large flask and inoculated with transformed *E. coli* (Section 4.12.1) containing a GFP reporter construct (*katE* promoter & GFP, Section 5.6) and left to incubate. The fluorescent light was visualised using a Darkreader (a transilluminator, blue-light with orange filters).

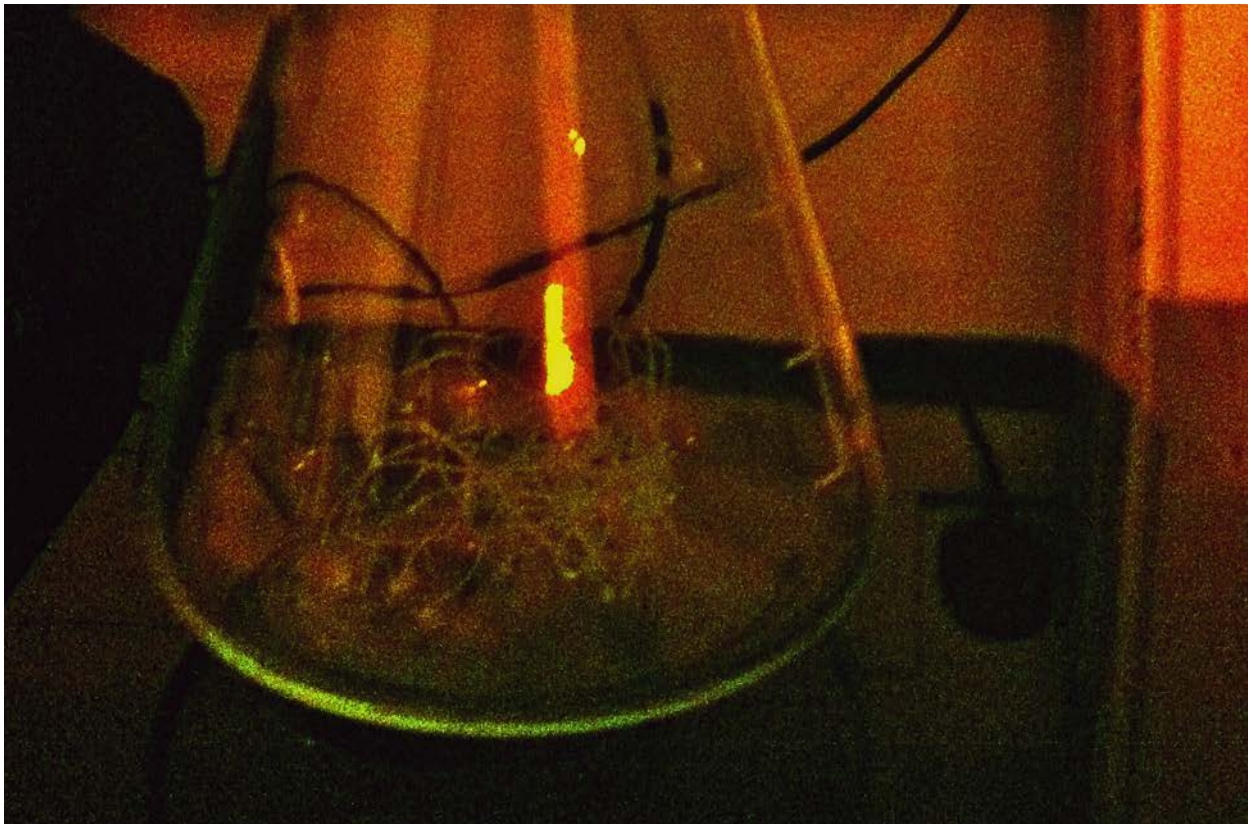

Illustration 27: *Suspended Lights*, experiment with fluorescent bacteria growing on agar-coated wires (fish wire). Photo: Howard Boland.

Given the challenge of sustaining sterile conditions in three-dimensional spaces, like *Bacteria World* (Section 5.3.1) there were no scientific guidelines for working with media in such manner. Shapes explored included tangled and vertical lines where bacteria would grow upwards from a base. Transparent fish wire had a reflectivity quality but gave the best results in terms of bacteria appearing suspended. Copper had the advantage of being malleable but a uniform agar coating could not be achieved. Future scopes include coating via drip feed or spraying media. Originally, it was also thought to involve natural materials, such as spider webs, providing unusual visuals. As an experiment, it reflects on growth and considers how strings may be used as restrictive spaces to explore behaviour in bacteria (see also Section 5.9).

## 5.4 Towards growth as behaviour in bacteria

While exploring growth through expanding colonies to generate visual and experimental displays, it did little to address variations in growth in terms of behaviour. Such potentials of eliciting behaviour in *E. coli* were explored through swarming (Illustration 28) and chemotaxis (i.e. ability

of bacteria to direct movement towards or away from chemicals). Chemotaxis and swarming[102] in *E. coli* is a well-studied area (Darnton et al., 2010) but visually less dramatic than many other organisms (e.g. slime mold or sperm swimming to egg).

In keeping with *E. coli* as a model organism, the research probed the extent colonies could produce goal directed behaviour through growth. Observing bacteria in a petri dish must be understood as a system responding to signals since a single colony contains billions of cells (Mashimo et al., 2004: 201). Not surprisingly, researchers have described this as a type of social behaviour and even intelligence (Jacob et al., 2004: 239-263) through interactions taking place on genetic and chemical levels. On a petri dish, conditions become dynamically altered when a single colony expands and central regions are deprived of nutrients. As conditions change, populations migrates by dividing and swimming towards nutrient rich territories or away from detrimental areas. In specific situations, bacteria begin to rapidly change their morphology and this can be seen as distinct changes in growth producing fractal patterns through a behaviour known as swarming. At the migration front, specific genetic and environmental signals cause elongation of the cells and introduce changes to flagella that give rise to new swimming patterns (Illustration 28).

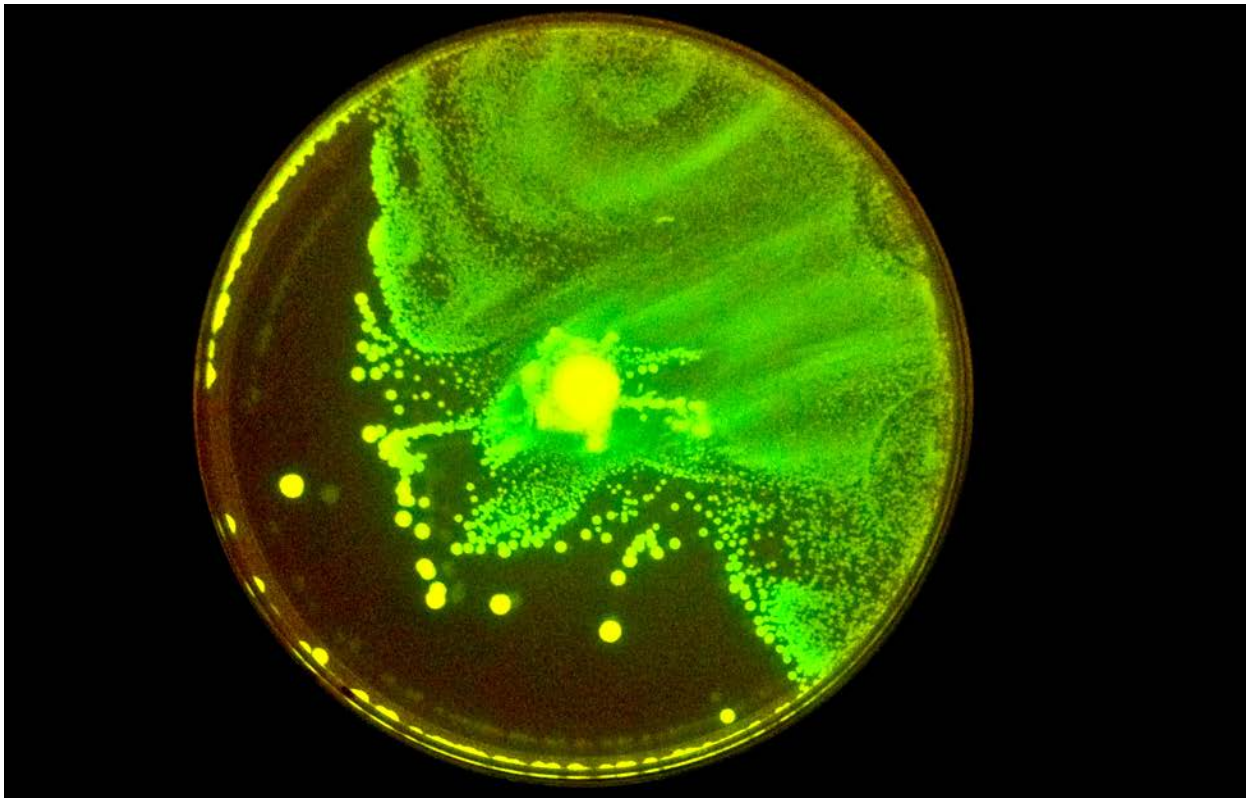

Illustration 28: Swarming *E. coli*. Photo: Howard Boland.

[102] Notably, swarming without chemotaxis is possible in *E. coli* (Darnton et al., 2010).

Experiments to explore swarming in *E. coli* were done using soft agar plates (Section 4.15.2). Semi-solid agar allowed colonies to translocate rapidly while keeping the agar moist. Initial tests involved inoculating petri dishes with *E. coli* and growing the colony over a three-day period (Illustration 29). Observation and photography were done on a daily basis. Later, a time-lapse facility was built providing a better understanding of how colonies form and extend. During observation, fractal patterns and petal-like formation emerged at the migrating front as colonies reached around 2 cm in diameter. These experiments reflect on differentiation in colonies between early to later morphology and led the research into its major study by looking at the possibilities of tapping into such changes using genetics (Section 5.6).

Illustration 29: *E. coli* colonies after three-days of growth. Photo: Howard Boland.

## 5.5 *Sugar Rush*

Pattern and differentiation in swarming was expanded to include chemotaxis experiments using sugar enrichments. In initial experiments a droplet of concentrated sugar (1 µl of 1 M Glucose) was added to the centre of a petri dish containing LB-agar and *E. coli* inoculated around the circumference in a distributed clock-like manner. The experiment showed bacteria migrating towards the centre in a broad line producing a fractal-like formation (Illustration 30).

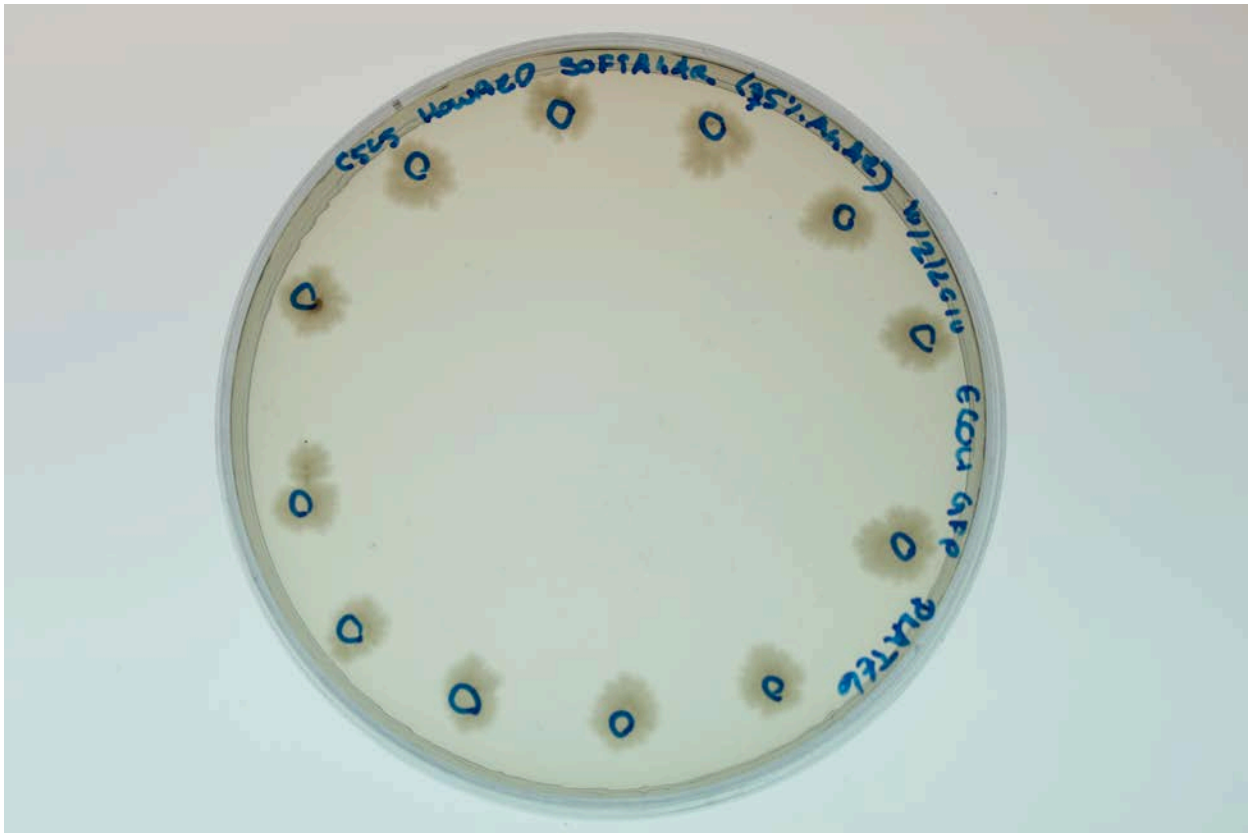

Illustration 30: *E. coli* growing from circumference with sugar droplet in centre (1 µl of 1M Glucose). Photo: Howard Boland.

*Sugar Rush* plays on a common myth associated with children, suggesting a high intake of sugar makes them seemingly excited and behave erratically (Gibson, 2007). The work carries double meanings that (1) giving these bacteria a sugar rush will similarly produce a sort of fractal and erratic behaviour as cells rapidly drive themselves towards these sugars and (2) reflecting on idiosyncratic methods used by artist in the laboratory that may leave them alienated or ousted as 'children' in scientific laboratory contexts.

Petri dishes containing soft agar (Section 4.15.2) was prepared by cutting out five rectangular pieces of agar around the circumference (approx. 1 cm by 0.3 cm). Five flask of hard agar, each containing the same concentration (1M) of the respective sugar (e.g. glucose, fructose, galactose, sucrose and maltose) and a unique visual indicator using food dyes were prepared, poured into the cut holes and allowed to harden (Illustration 31). Inoculum of *E. coli* was added to the centre of the petri dish and left to incubated for 3 days. The experimental result showed a preference to glucose. As time progresses food colours indicated diffusion of the sugar rich agar into the adjoining media.

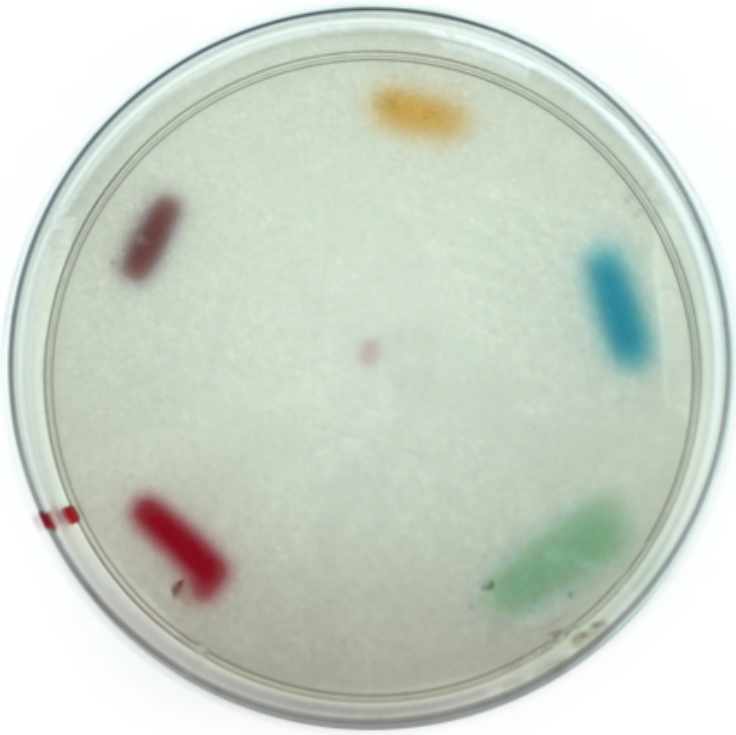

Illustration 31: *Sugar Rush* set-up on a petri dish. Colours denote the following sugars: Red is Galactose; Brown is Maltose; Yellow is Fructose; Blue is Sucrose; and Green is Glucose. Photo: Howard Boland.

As in previous outcomes (e.g. *Bacterial World*), *Sugar Rush* creates a living information display where the data (i.e. a colony spreading in response to chemical attraction to sugars) is embedded in the system (i.e. specified by evolutionary metabolic adaptations) and can be visualised with the naked eye as a whole system of bacteria moving towards the attractant in spite of emerging from capacities within each bacterium. The system is closed, dynamically adaptive and based on emergent life processes rather than a simulation of these. Thus, its shares many characteristics with generative and evolutionary art, however, these focus more on algorithms and computational factors as a source of autonomy from the artist (Galanter, 2008: 317). *Sugar Rush* and more so in later outcomes harness a visual experimental design rationale to bridge telling phenomena in bacteria that in this case bring about understandings of goal driven behaviour in cells.

While early experimental works (e.g. *Bacterial World*, *Suspended Lights* & *Sugar Rush*) use scientific methods, they also deviate from standard scientific practices and develop their own idiosyncrasies. Operating outside norms is accepted and even a common practice within the sciences (sometimes aiding new discoveries). However, when non-scientists impose idiosyncrasies this can be perceived as 'suspect' and even 'corruptive' to scientific research

(making science less 'serious' but perhaps more interesting). To an extent, this research is aligned with Latour's analysis of the scientific community as operating in a tribe-like manner (Latour and Woolgar, 1986). As part of a two-year ethnographic inquiry (1975-76, Fulbright scholar) at Jonas Salk Institute for Biological Studies[103], Latour proposed an understanding of its scientific community as tribal, meaning it adhered to a specific set of rituals understood by those on the 'inside'. Further, he suggests that 'outsiders' are viewed as lacking the knowledge and value set to understand those on the 'inside' (Latour and Woolgar, 1986: 19-20, 111-112, 279). This 'inside-outside' alienation was experienced during this practice. Particularly in early stages, the use of photography, drawing and open-ended experimentation was seen as 'outside' activities to the laboratory.

Use of artistic methods (e.g. drawing, photography) were seen as 'child-like' by other laboratory members since it involved a level of play, an approach not common to their practice (Figure 13). This research considers how artists work their way into a scientific context by hybridising methods to establish an independency.

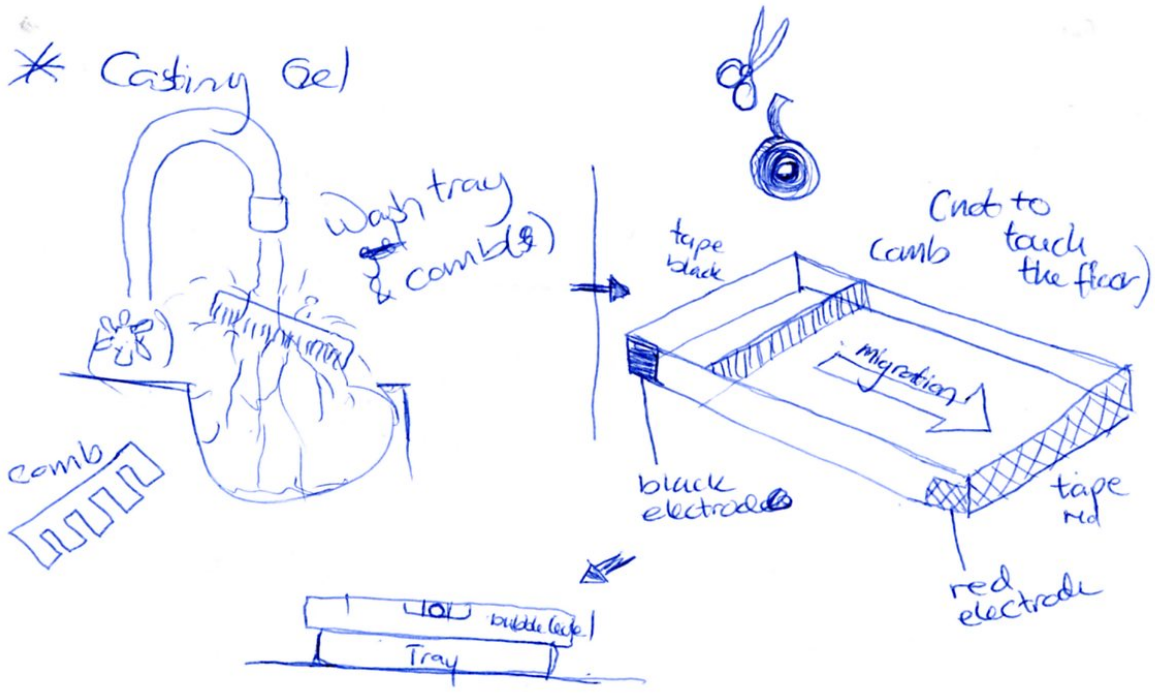


Figure 13: Sketching out procedures. Photo: Howard Boland.

As discussed, this involves a great deal of learning and, like undergraduate students in the sciences often entering the laboratory for the first time, there is a 'child-like' openness given the

[103] Neuroendocrinology laboratory of Professor Roger Guillemin in La Jolla, Cold Spring Harbour, US.

inexperience and desire to learn. Yet, in the case of science students, such behaviour is granted as they are becoming trained in procedures adhering to the rituals and values accepted within the 'tribe'. The cultural clash may therefore, at least at the onset, be challenging for artists as they are understood as 'outsiders'. However, as this practice expanded through its immersion to incorporate a broader set of methods and understandings, it gained a competency to operate independently within the sciences and established the necessary hybrid skillset to develop artistic research outcomes. Thus, this research suggests that there are more actors than those on the 'inside' and 'outside'. In other words, as a binary analysis, Latour's understanding of scientific communities as 'tribal' is in line with Snow's critic of science and humanities (Snow, 1959) (though later revised) and this does not provide an adequate account of how such communities are evolving – at least in the longer term. Rather, it is likely that more actors will fill in-between gaps and provide a more creative atmosphere. For artists to partake in formulating how the culture of these communities are shifting, there is a need to actively acquire languages and tools that operate across these domains.

What was consistent throughout the practice was that scientific immersion impacted aesthetics and becomes an integral part of its formulation. Experiments were devised to partake in the exploration of living fabric to generate 'knowledge narratives' that combine scientific knowledge production with composition of narratives. Taking into account the immediacy of living matter and its behavioural complexity, the practice uses a material language (i.e. bio chemical components) to open a communication scenario to elicit knowledge and narrative. As such, it attempts to depart from endeavours aimed at reflecting on human conditions alone by expanding understandings of the non-human (Chapter 3). The hybridisation of scientific functional design with material compositions was aimed at integrating the living and its expression to bring about significations. Scientific quantification becomes experientially enriched as qualitative data rekindles curiosity and imagination too often lost in numbers and graphs (despite their importance) by using the material itself as the source of knowledge. This principle of using behavioural or substances generated by the organism to tell its own story is central to the experimentation. Thus, the dive into the molecular offers a broad scope of exploring such materials, not only through elicitation but also through the creation of novel behaviour in the living.

## 5.6 *katE*

### 5.6.1 Background - visualising growth using genetics

Expanding experimental studies in growth and differentiation, this research proposed to create an indicator, such as a protein or a pigment, to provide observational feedback of changing invisible states in bacteria. It suggested that this change could be captured to generate a visual difference similar to how tree-rings provide a visual knowledge source (i.e. dendrochronology). Growth cycles are also found in bacteria (e.g. lag, exponential, stationary and death phase) but are normally understood as a closed systems that 'phases-out' to a final state (Figure 16) rather than oscillating patterns through seasonal shifts as with tree-rings.

Following on from learning recombinant technology (Section 4.12 & 4.13) and exploring possibilities in growth and behaviour (Section 5.3 & 5.4), the major study and practical undertaking of the research will be outlined. The work was divided into four phases, with two major outcomes titled (1) *katE* (Section 5.6.9) and (2) *Stress-o-stat* (Section 5.7). As will be shown, *katE* provides the foundational material to develop *Stress-o-stat* but a division in discussing these works is appropriate since it involved substantial changes in methods used and outcomes.

*katE* looked at growth and behaviour informed by recombinant potentials of seeing growth changes over time. The aim was to build a genetic system that could create an indicator mechanism to visually capture stagnant versus exponential growth. While many alternative possibilities exist for this work (writing in retrospect), it was at the time an insurmountable challenge and it was not clear how to develop such a system from a genetic perspective. Thus, the project began with preliminary computer-generated visuals (Adobe Illustrator & Adobe Photoshop) to enable discussions. The visual (Figure 14) suggested a growing colony capable of changing colour as it changes from one state into another.

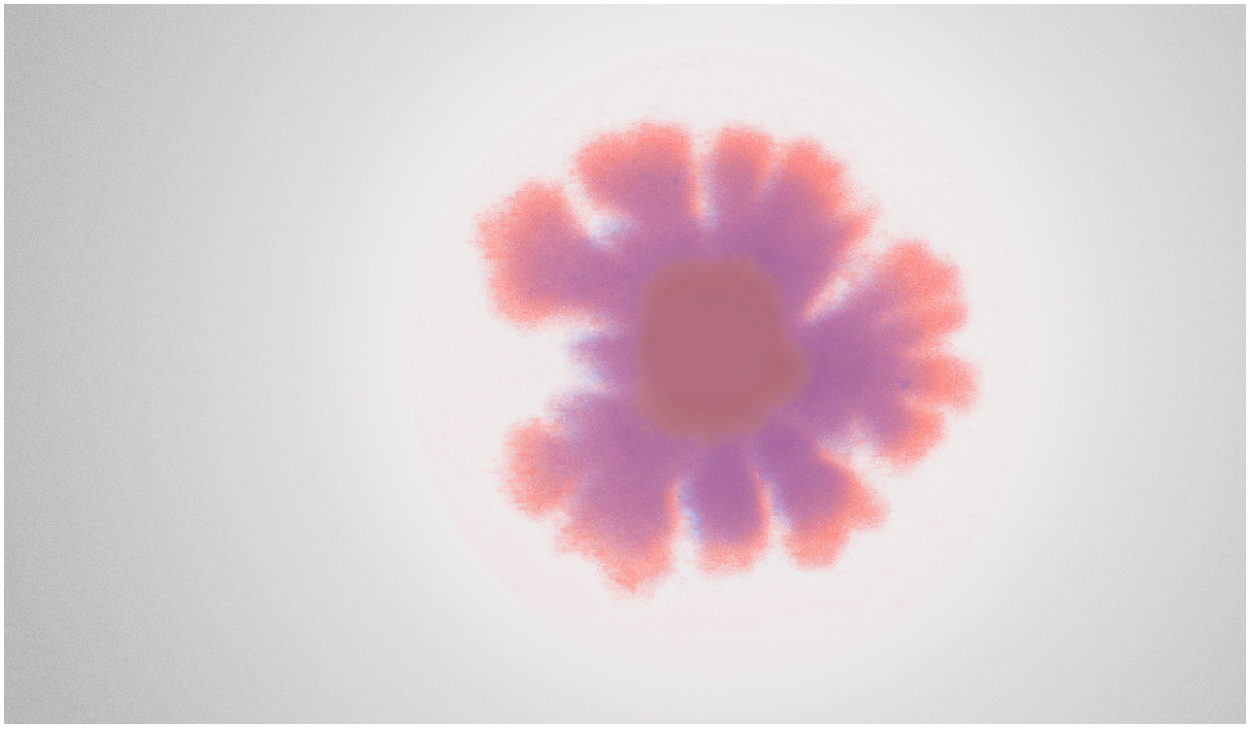

Figure 14: *katE* preliminary visuals. Overlaying, masking and colouring photos from growth studies using a photo processing software (Adobe Photoshop) suggested the type of visual the project would generate. Illustration: Howard Boland.

Initial ideas also included integrating a time-lapse device called a *Growth-barrel* (Figure 15) used to capture growth processes over time. While the set-up is outside the discussion of katE, a similar system built during the research will be discussed (Section 5.13).

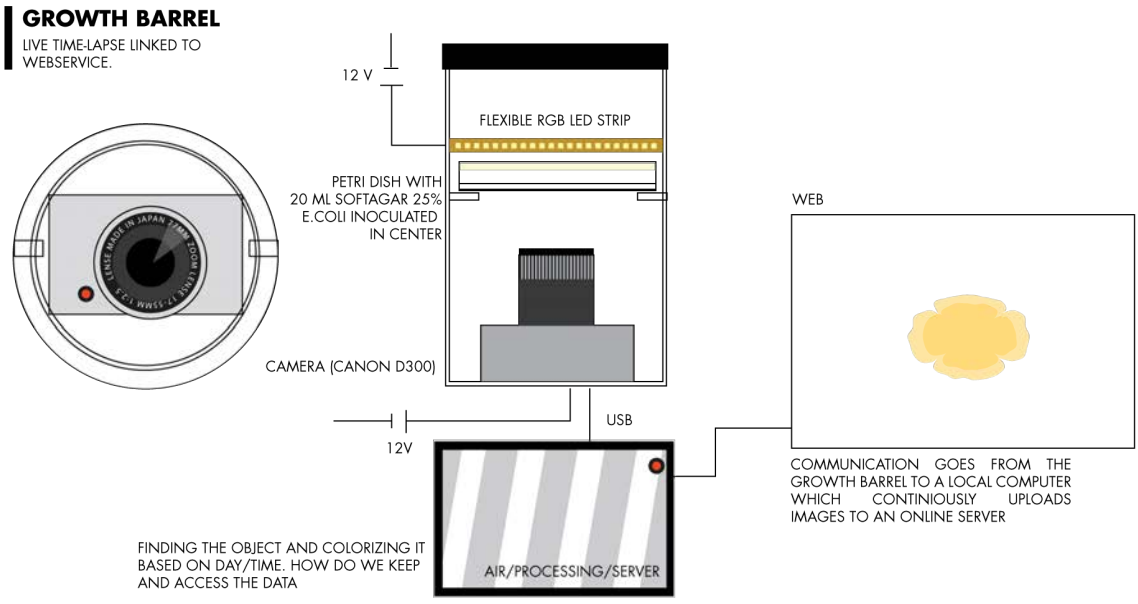


Figure 15: Initial proposal to integrate time-lapse device. Illustration: Howard Boland.

### 5.6.2 Growth states

The concept of 'state' is used across disciplines and includes formal mathematical descriptions. Used here in an intuitive manner, it can be understood as a change in time, observation and based on control parameters, loosely connected to formal descriptions (e.g. finite-state machines). Often biological systems have statistical threshold factors, for instance during growth there are rapid periods of transitions followed by longer periods of stability (see Figure 16).

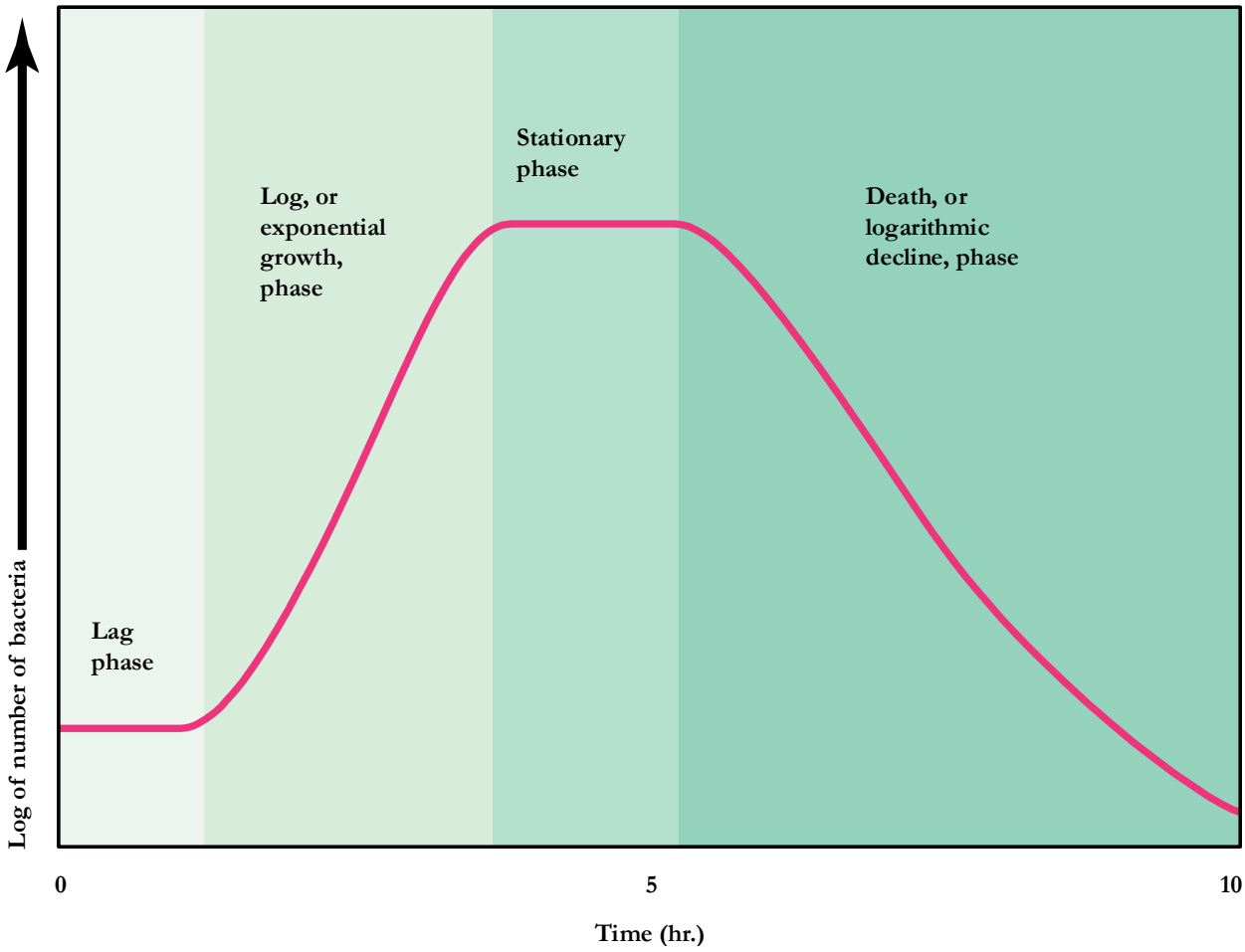


Figure 16: Bacterial growth through four phases. Figure adapted from Michał Komorniczak (Komorniczak, 2009) and licenced under creative commons.

The periods of stability between these transitions are what I will refer to as 'states' in this context; however, periods of distinct instability can also be understood as a state (e.g. non-linear systems). Alternatively, we may consider a state as a distinct node with access to a discrete number of other states through a transition phase. In order to formulate these concepts in terms of colony development and the proposed visual (Figure 14), the research asked what concrete states exists or become triggered on a genetic level allowing differentiation to emerge. As with earlier experiments (Section 5.4), the movement of growth beginning from a single point of

inoculum expands as the culture grows and migrates radially until it reaches a point of transition. Considering this movement over time, one change that occurs is the depletion of nutrient at the centre of the colony, since cells are spending more time in this area. It was expected that a threshold value would begin to emerge from the centre resulting in a phase change that demarcates it from the migrating areas, thus producing two different states. As indicated, this suggested a difference in metabolic capabilities that could be tapped into genetically by looking at discrete components involved in cell metabolism during low and high nutrient accessibility.

### 5.6.3 *katE* – the gene, its function and promoter

As discussed in section 4.9, promoters are potential candidates that may be used to tap into genetic signals. Of interest were promoters activated during food deprivation. As it turns out, food depletion involves a chain reaction of events making the identification of a single promoter challenging. However, the search for a promoter normally starts by looking at genes (i.e. protein coding genes) that generate protein or enzymes capable of performing cellular tasks such as synthesising or breaking down chemical matter.

A literature search identified a good candidate, *katE*, a gene responsible for the production of an enzyme (Catalase HPI) used to reduce oxidative stress (Figure 17). While there may be many causes to this type of stress, a common factor is depletion of nutrient since it destabilises energy conversion in cells (e.g. electron transport chain) leading to free radicals, first through the production of superoxide ($O_2^-$) that in turn reacts with water to produce hydrogen peroxide, a substance detrimental to the cell.

In its evolutionary genomic integration, transcription of *katE* into Catalase converts hydrogen peroxide into water and oxygen. Thus, the aim was to locate the promoter that drives this gene expression. Using *katE* promoter to regulate expression of an alternative reporter gene (i.e. a *gfp* gene to produce GFP proteins capable of emitting light when excited at a certain wavelength), a light could be produced during activation of stress response. The system would form an independent genetic circuit that would work in tandem with the genome and indicates when cells are experiencing oxidative stress.

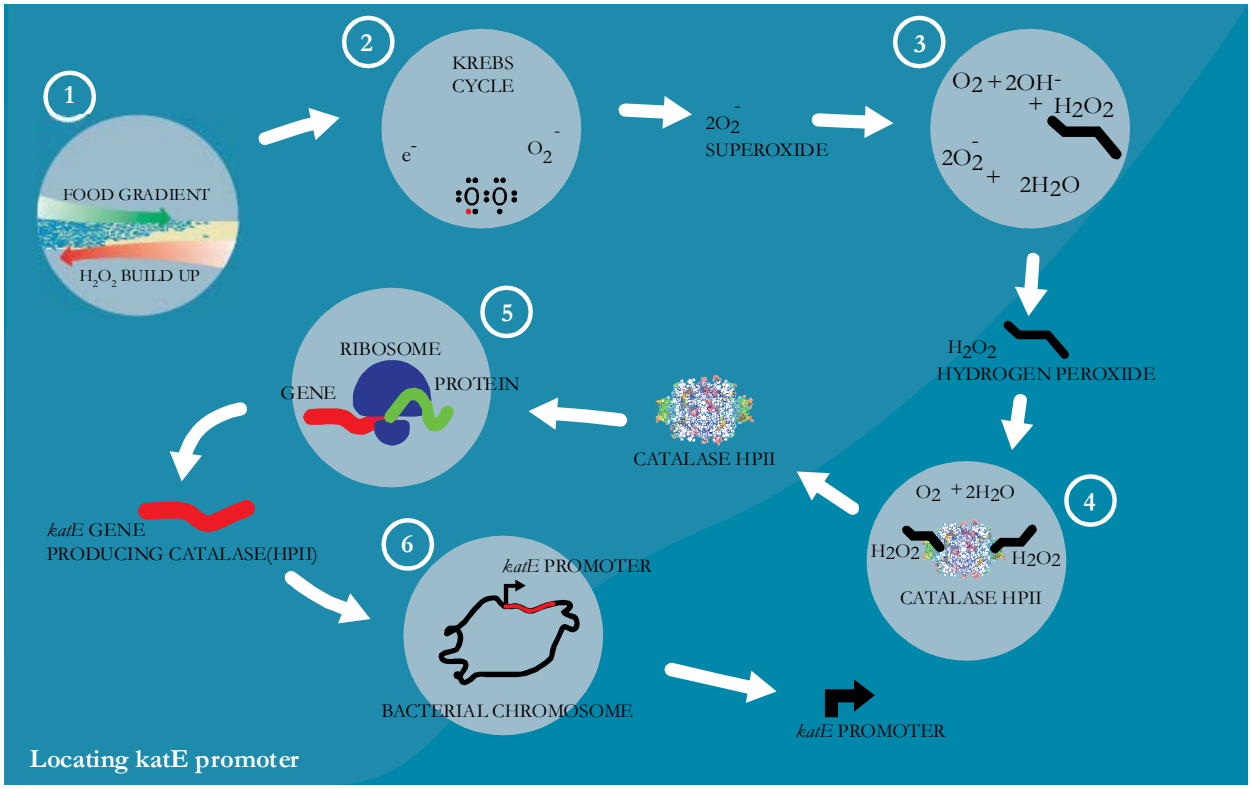


Figure 17: Locating the stress promoter was done following the above logic: (1) Decreased food supply. (2) Lack of glucose can cause homeostatic processes such as the electron transport chain to destabilise. For instance, the cycle may not have all the elements needed to complete ATP production. This can increase electron leakage and cause oxygen to form the compound superoxide. (3) In turn, superoxide readily reacts with water, giving rise to potential cell damaging substances: hydrogen peroxide and peroxide. (4) The molecule Catalase (HPII) converts hydrogen peroxide into water and oxygen. (5) During stress, the cell increases the production of Catalase (HPII) by also involving a second enzyme superoxide dismutase. (6) The bacteria chromosome contains a promoter for a gene called *katE* that is activated during transcription of Catalase (HPII). Illustration: Howard Boland.

### 5.6.4 *katE* - genetic assembly

The development process can be split into phases involving design, synthesis, material exchange, amplification, purification and assembly. As described in Chapter 4, this involves bioinformatics (Section 4.11) to identify both the promoter and reporter construct.

The reporter construct was identified in the paper 'A comprehensive library of fluorescent transcriptional reporters for *Escherichia coli*' (Zaslaver et al., 2006) as good candidate since the plasmid contained (1) a GFP mutant *(gfpmut2)* that rapidly fluoresce (within five minutes of transcription) in a highly stable and non-toxic form to cells, and (2) an open-reading frame (a section on the DNA where proteins can be encoded) to incorporate the *katE* promoter providing clear and succinct system for testing stress (Figure 18).

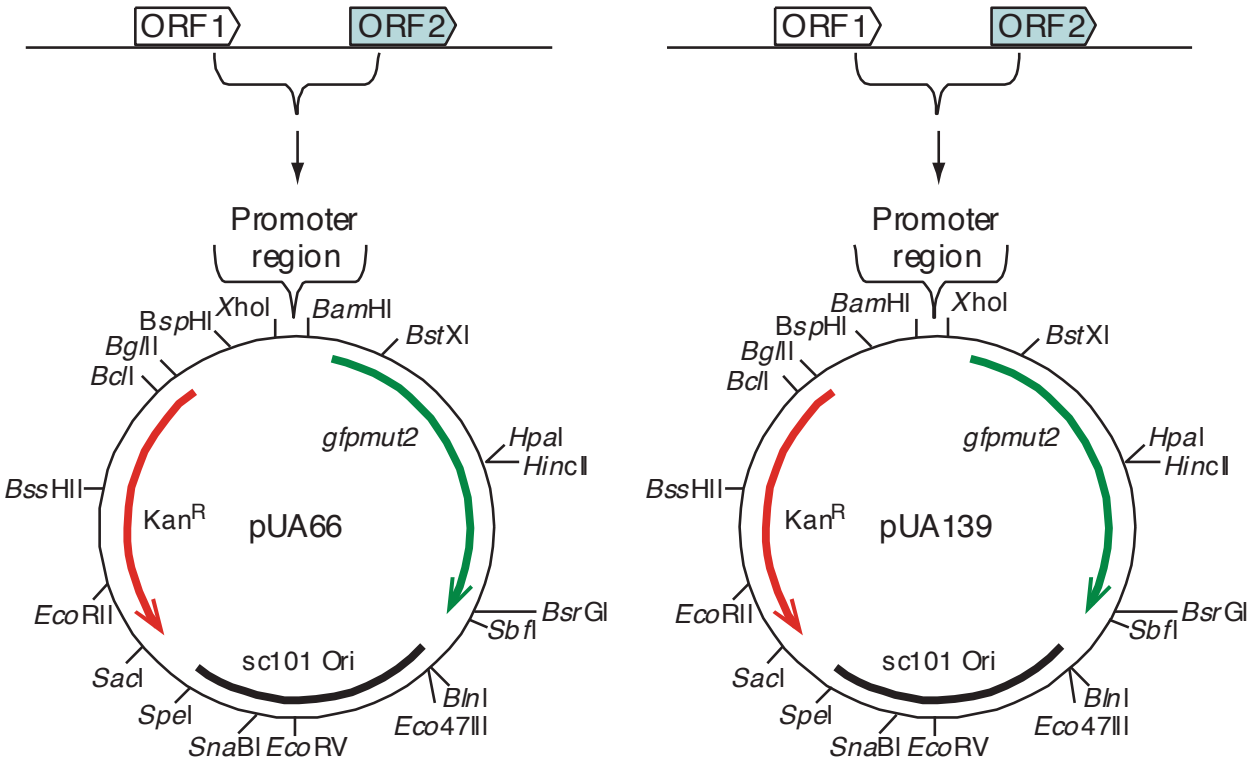


Figure 18: Both constructs contained the restriction sites BamHI and XhoI, however, the direction of these sites were such that the promoter could be oriented in either upstream or downstream direction (Zaslaver et al., 2006). Image credit: Zaslaver, Alon; Bren, Anat; Ronen, Michal; Itzkovitz, Ilya; Kikoin, Shalev et al., 'A comprehensive library of fluorescent transcriptional reporters for *Escherichia coli*', 'Nature Methods', vol. 3, issue no. 8, page 305. Reproduced with permission of Nature Publishing Group.

Two plasmid constructs (pUA66 & pUA139, 4260bp) were requested from the Weismann Institute (Israel), provided by the authors and shipped as agar stabs (Illustration 32).

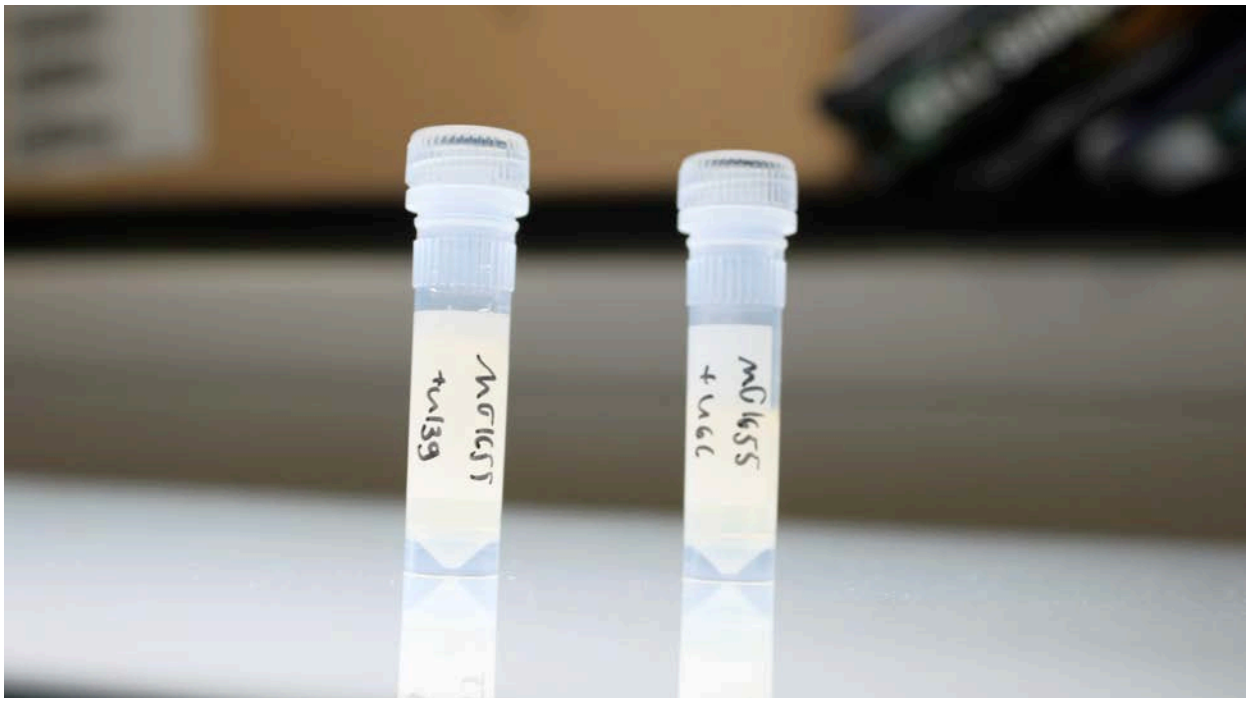

Illustration 32: Tubes of agar stabs containing two plasmids (pUA66 & pUA139) from Weismann Institute. Photo: Howard Boland.

The stab cultures were transferred and streaked out onto fresh plates containing antibiotic (Kanamycin) and then grown, purified and digested as described in sections 4.12.3 - 4.12.12. However, this had to be iterated several times as these plasmids turned out to be low-copy number (5-10 copies as opposed to 200-1000 copies per cell used prior to this experiment). The low-yield made it difficult to see bands and confidently excise these from the gel. An alternative kit (i.e. QIAgen miniprep kit) was used and attempts were made to concentrate samples using a vacuum centrifuge to evaporate water while retaining plasmids (Appendix XVI). The new kit proved efficient and produced bands that could be cut and digested (Illustration 33).

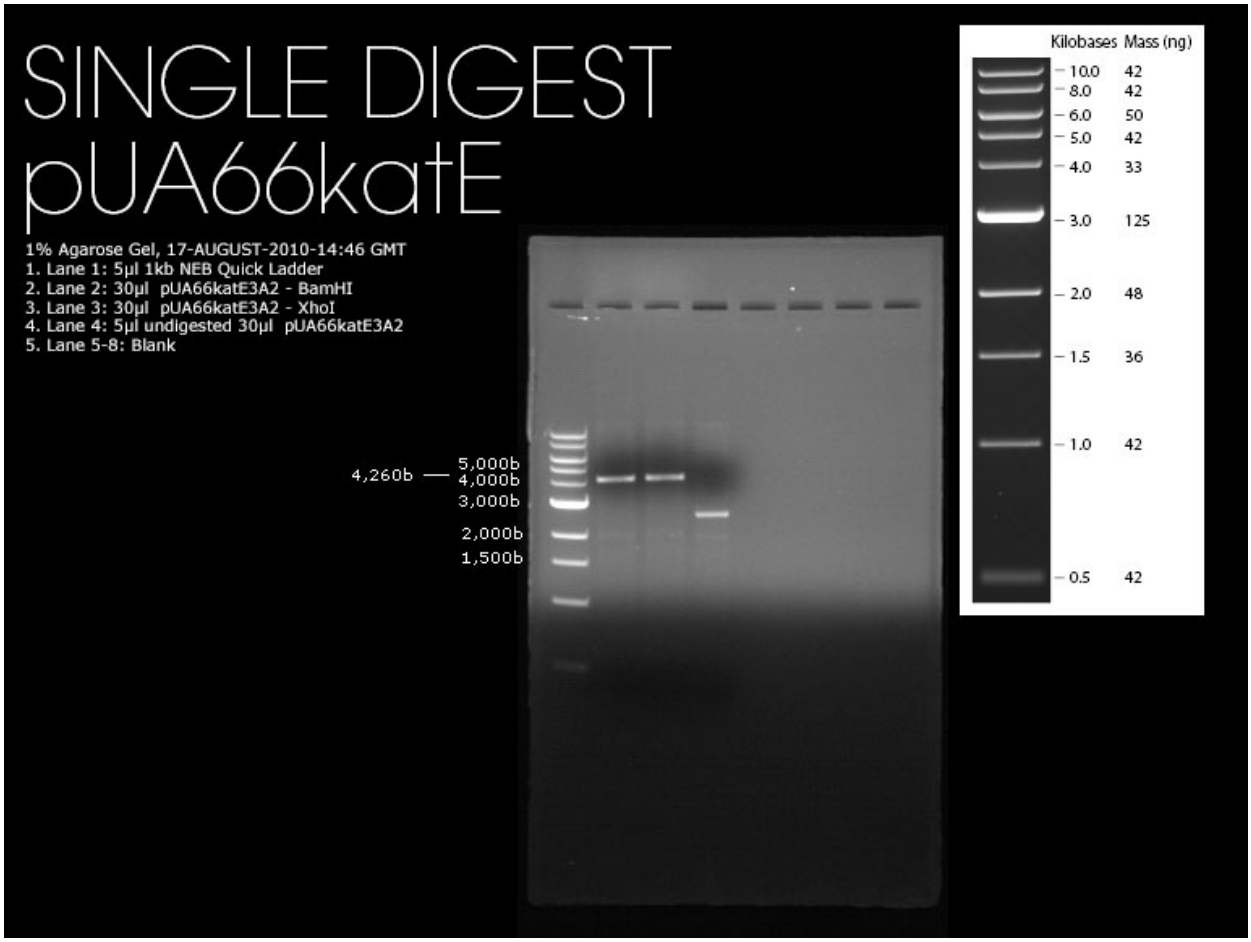


Illustration 33: Single digest of pUA66. Photo: Howard Boland.

Double digestion was inefficient and a serial digestion was performed using one enzyme at a time over longer periods (5-8 hours) than normal (Section 4.12.8).

Using the NCBI database (Section 4.11) allowed identification of the *katE* gene, its direction and adjacent gene *cedA* (Figure 19).


Figure 19: Directionality of *katE* suggests its promoter can be found upstream. Further its adjoining gene *cedA* pointing in reverse direction suggests a single promoter control can be found between these genes (NCBI, 2012b).

The aforementioned paper (Zaslaver et al., 2006: 627) suggested a method for locating a viable promoter by selecting a sequence in the (intergenic) region between the two adjacent genes *katE* and *cedA*, by extending into these genes by 50 to 100 base pairs (Figure 20).

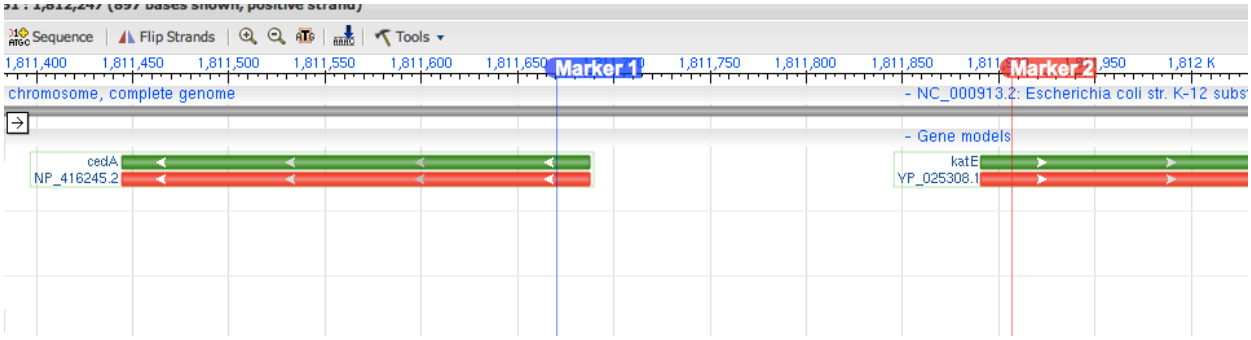


Figure 20: Sequence explorer with added selection markers showing the region where *katE* promoter was likely to be found between Marker1 and Marker2 (NCBI, 2012a).

Primer design was prepared (Section 4.11) with flanking restriction sites (BamHI and XhoI) to enable *katE* promoter to be extracted and cut. Extraction of the promoter used PCR where *E. coli* genome served as the template (Section 4.12.16). The colony PCR generated an expected product size (450bp) clearly visible on an agarose gel (Illustration 34).

Fusing the promoter to the GFP reporter construct was challenging and several attempts resulted in self-ligation where plasmids concatenated without the promoter insert. One test was simply to screen for GFP expression (using UV light) however this was not observed and it was thought that a chemical inducer was needed to activate the promoter (i.e. by adding hydrogen peroxide). Instead, a series of iterations were done by picking colonies, growing these up, purifying and digesting plasmids until a candidate containing the promoter insert was found. The debugging process was daunting and developed a growing tension with the material. Even when an insert was found there remained disbelief that these processes are partly guided by statistical 'luck'.

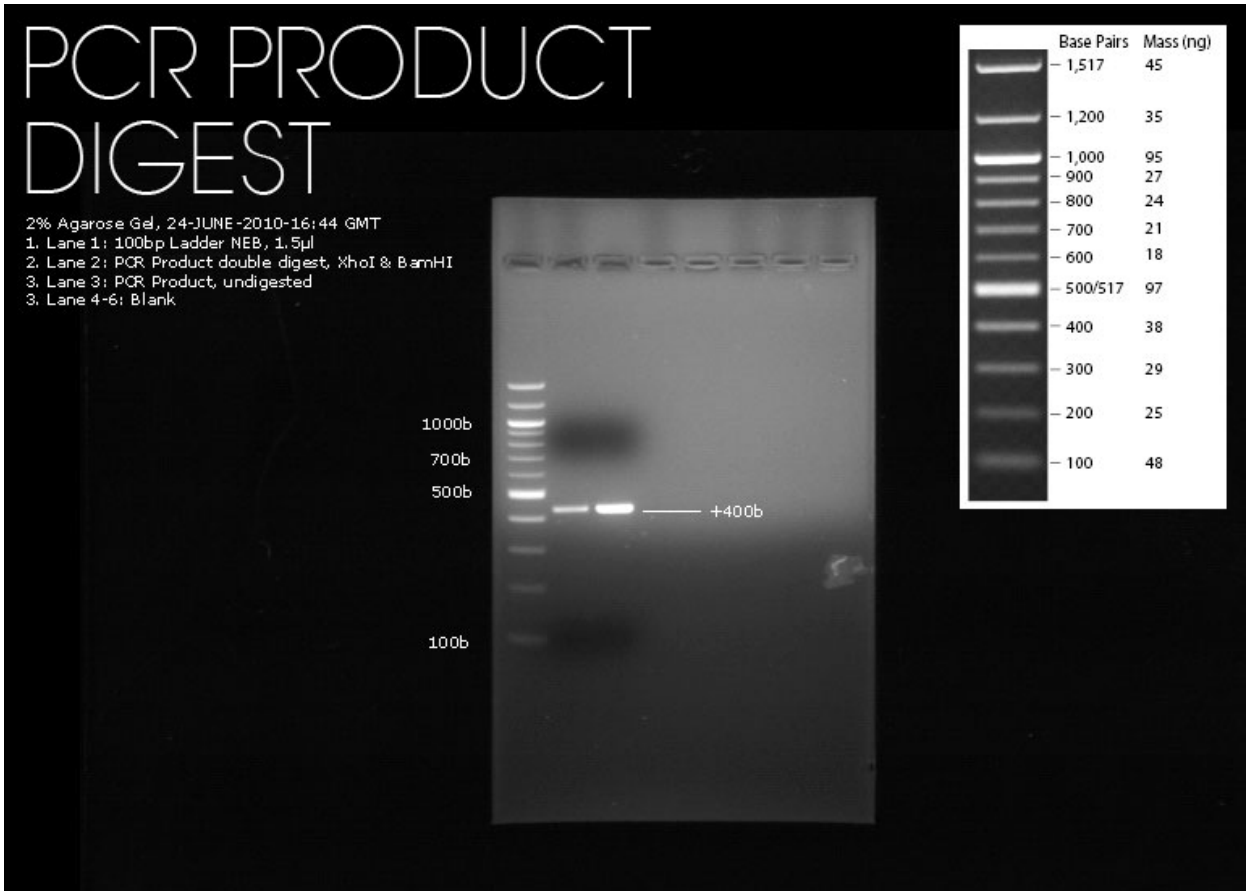


Illustration 34: 2% Agarose gel using 100bp NEB ladder, showing PCR product of *katE* promoter after digestion with XhoI and BamHI. Photo: Howard Boland.

After verification on gel, the next phase involved sequencing the construct (Section 4.12.18 - 4.12.19) using the primers for the *katE* promoter. A consensus sequence was generated (Section 4.11) using software to clean up and align the two sequence readings. This concurred with the promoter sequence and further provided enough data to indicate the start of the *gfpmut2* gene (in downstream direction). In spite of the exhaustive iterative exercise involved in the assembly, the success of the sequencing restored some confidence in the material.

### 5.6.5 Expression of GFP – the reporter mechanism

Looking at both colonies and broth, no observable fluorescence could be detected and fluorescent microscopy gave an unclear if not too weak result. Initially, a low-expression was anticipated, as *E. coli* in laboratory environment are normally given optimal conditions (e.g. nutrient, temperature and oxygen), it was thought that an inducer was needed for oxidative stress to occur. Using hydrogen peroxide in a serial-dilution, paper wafer disks of various concentrations were placed on bacteria lawn (Illustration 35) however none of the experiments resulted in fluorescence.

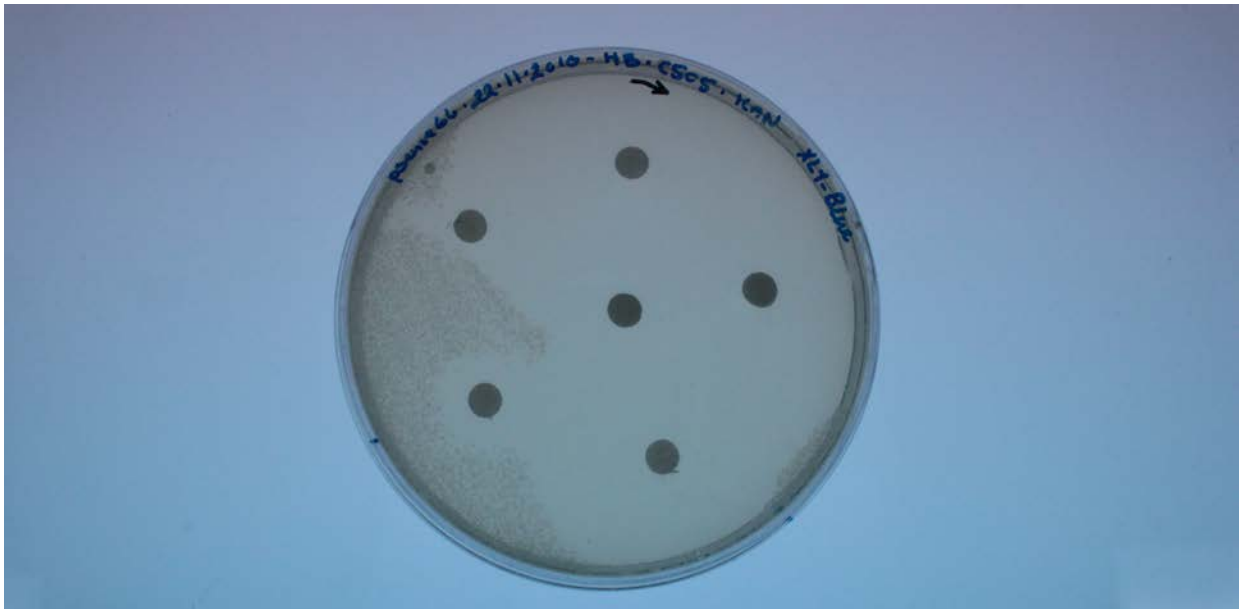

Illustration 35: Test using serial dilution of hydrogen peroxide by dipping paper wafers in solution and applying onto a lawn of bacteria. Photo: Howard Boland.

A Fluorometer Microplate Reader, a machine capable of reading values, used cultures grown with the inducer at various concentrations but returned low values. Finally, spinning down the broth and observing cell pellets showed fluorescent too faint to be telling (Illustration 36). In scrutinising the authors' paper and upon contacting them, it became clear that low expression was to be expected and a plate reader was needed to detect levels.

Illustration 36: Cell pellets after centrifugation show slight fluorescence but too low to be telling. Photo: Howard Boland.

### 5.6.6 Discussion: drawing the line between artistic and scientific aims

Obtaining numerical measurement provides an excellent method of sharing data amongst peers (Section 4.1 & 4.17), thus a machine read-out using standard 'inscription devices' is of high value in the sciences. While many scientific endeavours have produced high performing visual material, they are nonetheless focused on quantifiable data as an information source underpinning the scientific knowledge base. This is where the practice demarcates its artistic and scientific aspects since its aims were to experientially and visually explore phenomena by reducing the number of interfaces (including knowledge abstractions) between expressions generated by living components and the audience. Thus, the stress reporter (Illustration 36) construct would perhaps suffice for its scientific purpose but insufficiently addressed artistic aims.

On the other hand and in light of bio arts' celebration of visual drama often placing high visual demands onto the living suggests a need to consider ethical positions. It seems that such demands may subjugate life by emphasising aesthetic over ethical judgements and thus objectify life (Gigliotti, 2005). Thus, as part of reducing external interfaces to provide a material immediacy of these expressions it was needed that these were distinct and telling.

### 5.6.7 Phase 2: From low to high copy number

The most convincing reason for low GFP expression was the low-copy number origin (SC101 origin) of replication (Section 4.9.6) in the plasmid (pUA66). While no specific relationships exists (between the number of plasmids per cell and its expression as many factors are involved), it was suggested that if a cell contained 500 plasmids it was likely to have a 100-fold stronger expression than a cell harbouring only 5 plasmids. To boost GFP expression to become observationally visible, a proposed solution was to swap the low origin of replication with a high.

While new methods exist enabling 'hot-swapping' genes (Gibson et al., 2009; Haseloff et al., 2009), a straightforward approach involved amplifying two DNA regions using PCR. A large section was extracted from the low-copy number plasmid containing the stress reporter construct and its antibiotic cassette and another section from a high-copy number plasmid (i.e. pMAK512) containing the origin of replication (pBR322) (Figure 21). Methods described in section 4.11 and 5.6.4 were used to design and obtain primers to extract fragments from these plasmids.

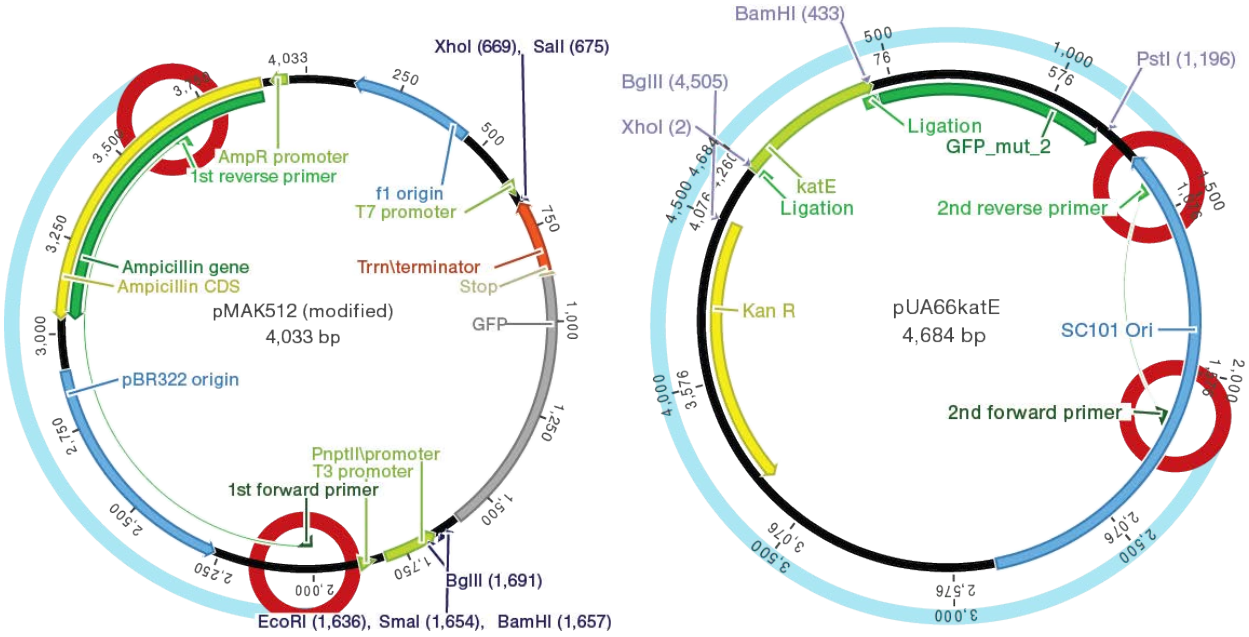


Figure 21: Left: pMAK512: PCR amplification steps into Amp gene. Right: pUA66katE: Long-range PCR where amplification goes into the SC101 origin of replication. The light blue lines indicate the areas of interest to be extracted from the plasmids. Illustration: Howard Boland.

The specific design implementation allowed self-ligation to be eradicated by antibiotic and origin of replication selection, thus only the right parts could come together since these contained the necessary components for the plasmid to function. These processes also allowed all primers to be designed with the same flanking restriction sites. PCR products were digested, cut and ligated (Section 4.12) with the resulting plasmid producing a significant improved yield and further evidence of the *katE* insert when digested (BamHI and XhoI) (see Illustration 37).

Unfortunately, while the newly assembled plasmids generated high-copy number and produced a strong band, in terms of GFP there were no observable differences. In spite of the considerable efforts already made, it was decided not to sequence this construct and change the research approach towards standardisation using synthetic biology.

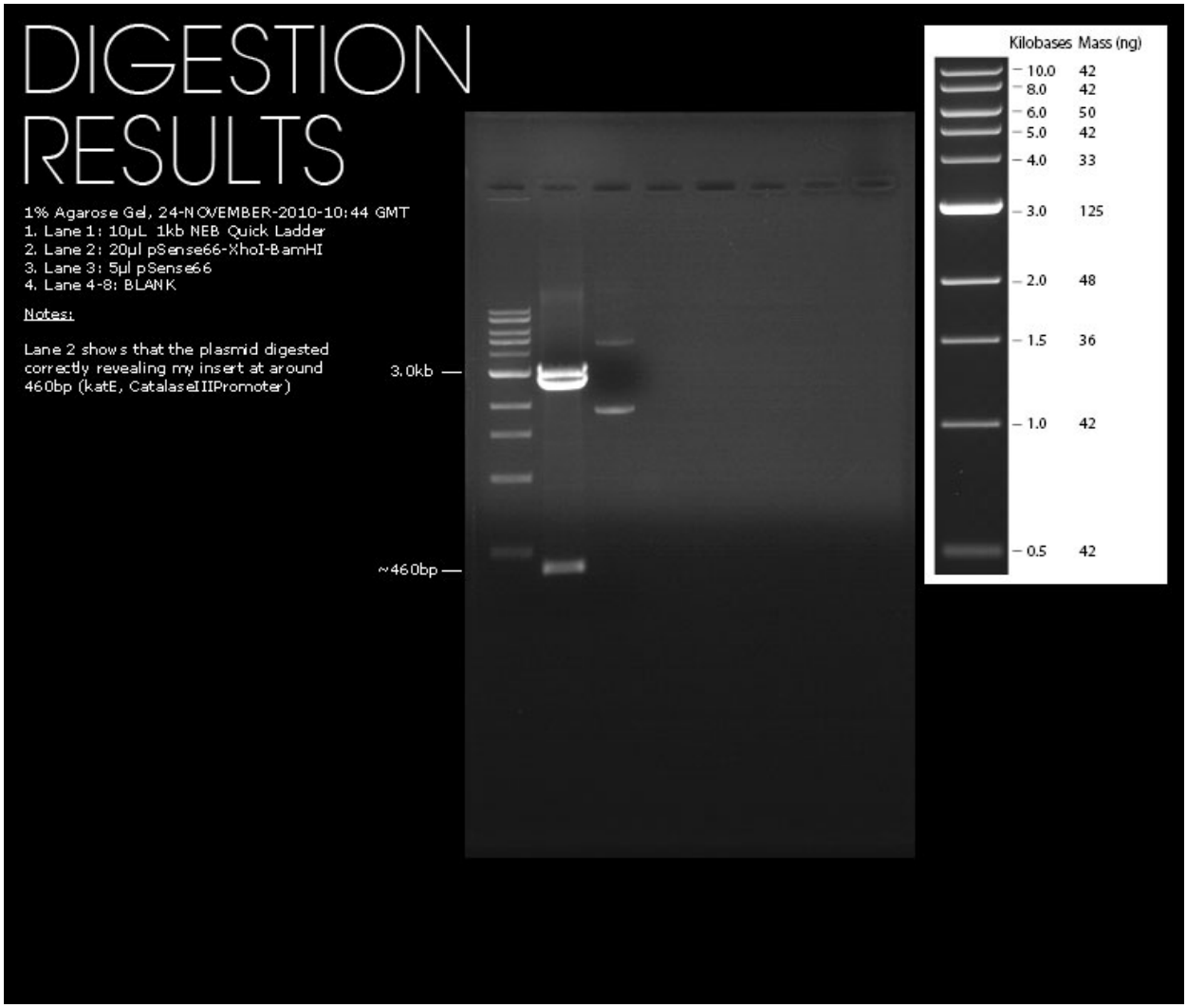


Illustration 37: UV-documentation of 1% agarose gel showing plasmid digested with XhoI and BamI, the *katE* promoter insert can be seen at around 450bp. Photo: Howard Boland.

### 5.6.8 Material crisis

Instead of producing more material whose expression remained uncertain, a revised strategy was put into place to ensure that outcomes could be achieved and work as expected. Several routes were considered and as a transition phase it generated many ideas extending the practice in new directions. For instance, using magnetotactic bacteria suggested interactive potentials (Section 5.11) and light pulsing bacteria generated through genetic constructs offered novel visual opportunities (Section 5.9).

Directing the research towards synthetic biology provided access to a wider range of material (e.g. the library of standardised parts) and involved registering the laboratory[104] with the synthetic

[104] Clements Lab.

biology network (e.g. Openwetware, the Registry of Standardised Parts and iGEM). Once obtained, several composite parts were tested to experience expression. To compare existing composites and ensure methods and subparts functionality, reassembly was done using idempotent methods (Section 4.14.2). For instance, the genetic construct BBa_I13522 composed of a GFP reporting construct (BBa_E0840)[105] and a constitutive promoter (*tetR*) was reconstituted (similar to tinkering, section 4.13) using these subparts to produce a bright yellow-green glow under UV light. Results suggested that the synthetic biology route would work faster and more consistently. Thus the primers for *katE* promoter was redesigned with flanking sites adhering to the RFC-10 standard allowing the promoter to be extracted as a BioBrick™.

### 5.6.9 *katE* using synthetic biology

Using the previously tested GFP reporter construct (BBa_E0840) with the standardised *katE* promoter part, a composite stress reporter was created following idempotent assembly (Section 4.13.2). Reassuringly, colonies showed GFP expression after overnight incubation of transformed cells (Illustration 38) indicating that these colonies were already experiencing oxidative stress.

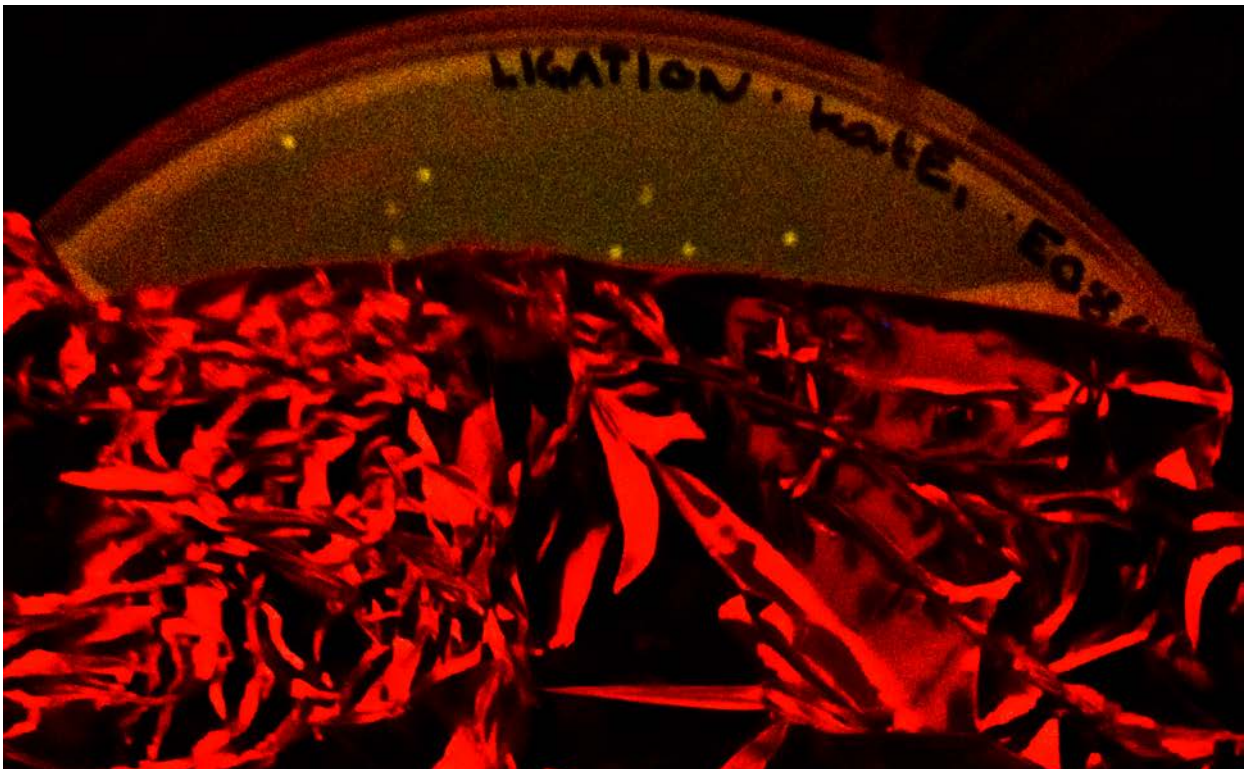


Illustration 38: *katE* promoter fused with a GFP reporter construct shows expression of GFP after transformation. Lower part of image (2/3) is reflection from foil caused by orange filter. Photo: Howard Boland.

[105] A composite containing ribosome binding sites (BBa_B0034), *gfp* gene (BBa_E0040) and terminator sites (BBa_B0015).

The construct was sequenced indicating the GFP construct had been incorporated as expected. With both bioinformatics and visuals conferring expression, it was possible to consider how a display could be produced to visualise stress behaviour. Returning to the original design proposal (Figure 14), this involved growing a colony over longer periods to see if differences could be detected. Similar to earlier growth experiments (Section 5.4), cells easily disperse around the petri dish making it difficult to control growth (Illustration 39). It was also unclear how to understand readings using the plate. For instance, it was expected that when nutrient was ample, expression of GFP would be lower than in depleted conditions. It was therefore thought that the centre of the colony would be brighter than the migrating front. However, since this GFP protein (BBa_E0040) was stable (half-life of 33 hours) and cells at the centre subject to lysing (or dying), the plate display was inappropriate for visualising stress.

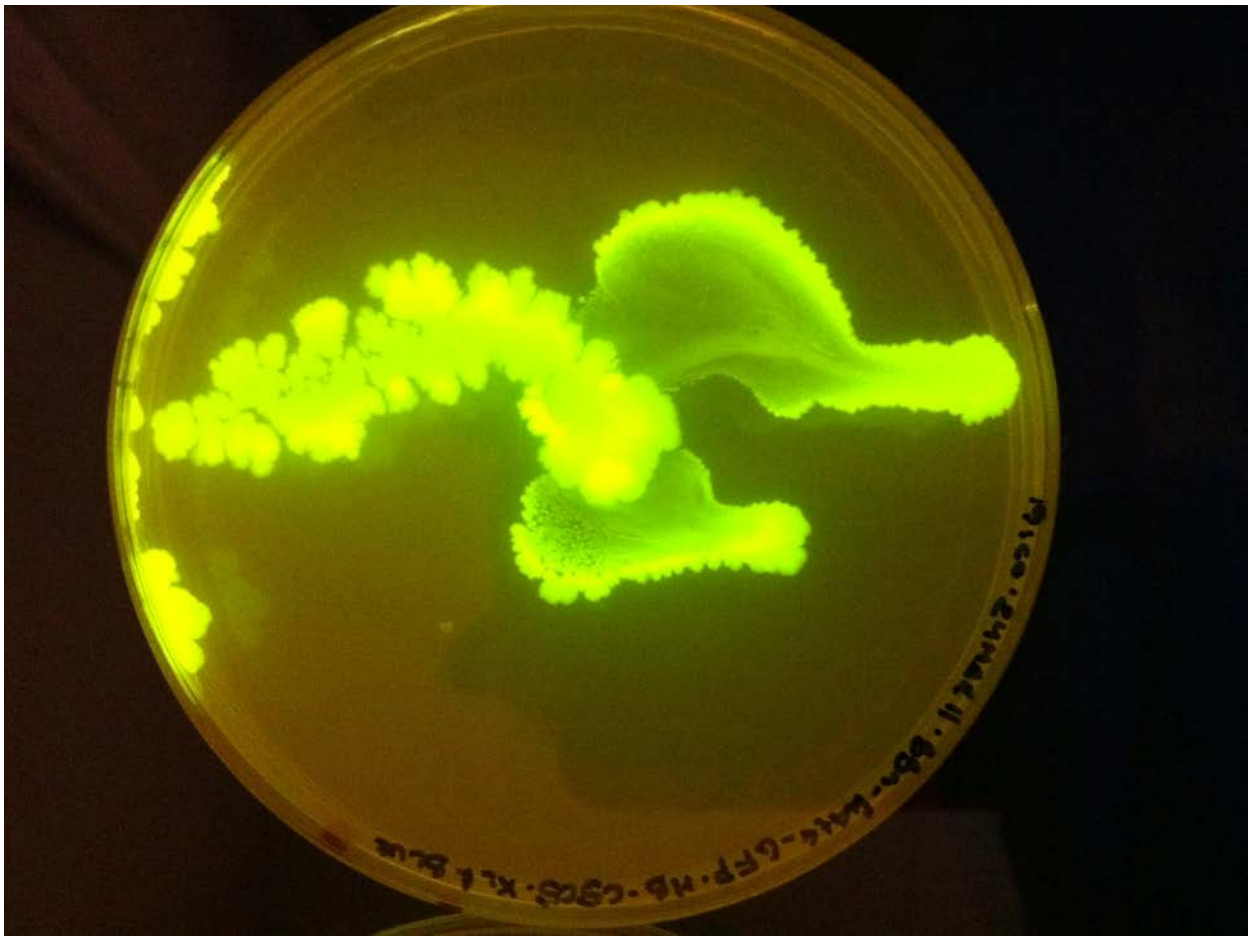

Illustration 39: *katE* promoter+GFP, grown over 5 days on soft agar. Photo shows early experiment using the stress-reporting construct to visualise stress-response in a colony expanding from a single inoculation on a petri dish. Moving the petri dish to and from the incubator to make recording made it difficult to keep growth steady on soft agar. Photo: Howard Boland.

And in spite of producing some interesting visuals, the work moved into a liquid culture where the population could be monitored and this work will be discussed in *Stress-o-stat* (Section 5.7).

However, a brief discussion of a later development (Section 5.6.10) involving the production of a similar construct using RFP (known as mCherry) is relevant since it adds additional consideration to the promoter activity in relation to protein production.

While it can be difficult to evaluate the effectiveness of the synthetic biology methodology compared to classic recombinant approaches due to a change in experience gained and the specifics of the assembly processes, these results suggested more robustness and predictability.

### 5.6.10 *katE* sees red with RFP

One of the reasons for changing the oxidative stress construct, *katE*, to express red fluorescence was to align the signification of stress with cultural understanding of colours. For instance, when humans are under stress, blood flushes to the face giving it a reddish colour particularly amongst those with paler skin. Also, red can be seen as an alerting colour and has been used as 'official' semantics in many apparatuses such as traffic lights, where it is used as opposed to green. While these factors play little biochemical role, they may impact our understandings. Further, a more visual reason for using RFP is its light pink colour visible in daylight as opposed to GFP that has a less distinct sheen under such light (Illustration 40).

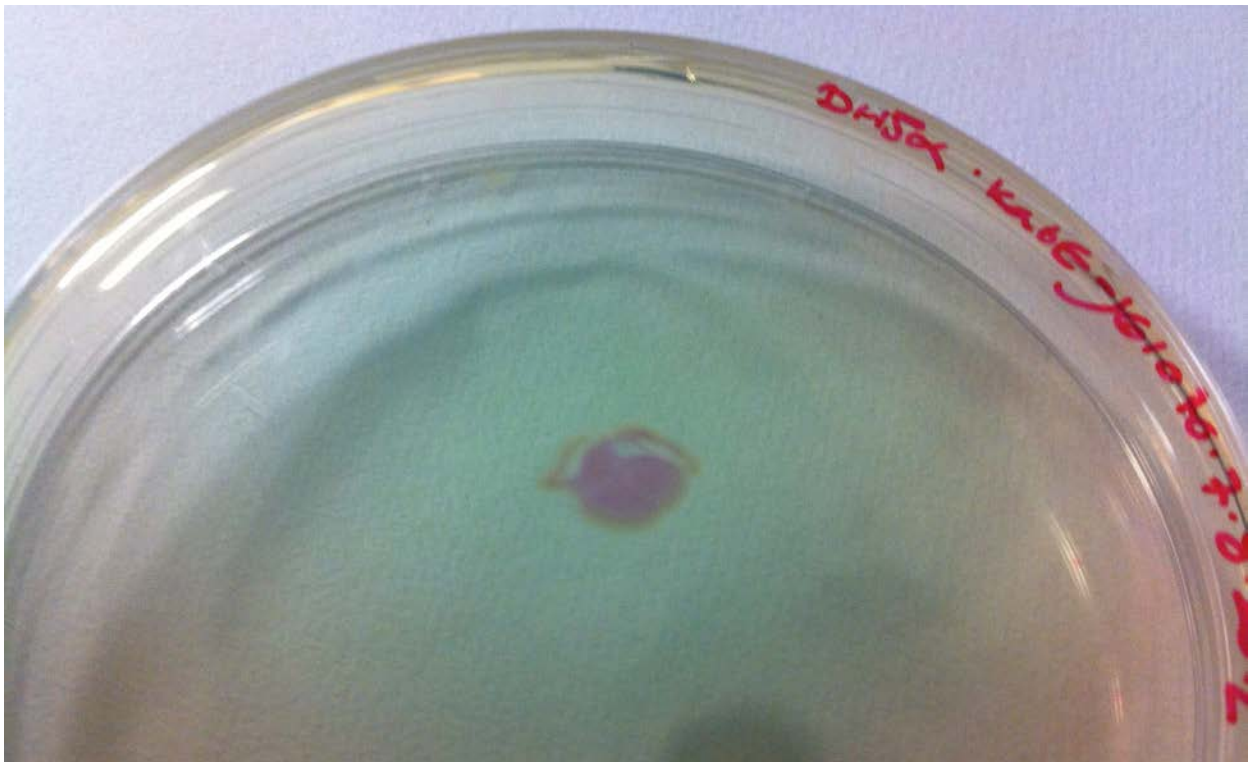

Illustration 40: RFP expressing *E. coli* seen under normal light (daylight). Photo: Howard Boland.

Similar to the GFP stress-reporting construct, the RFP construct (BBa_J06702) was assembled with *katE* promoter using idempotent design. This produced a weak fluorescent post-transformation. It was unclear why cells viewed under a microscope produced a more striking fluorescent using RFP than GFP but failed to produce visible RFP in liquid broth culture. Also, colonies showed less striking fluorescence with RFP (appearing pink) as opposed to GFP, however, when growing these over longer periods of time, a substantial pattern began to emerge. Using a swarming plate containing a rich top layer of agar and a bottom layer of hard agar, it was expected that a growing colony would have low expression of RFP, before emerging stronger as the plate dried out. The outcome showed a striking display producing an edge of fluorescence at the migrating front (Illustration 41).

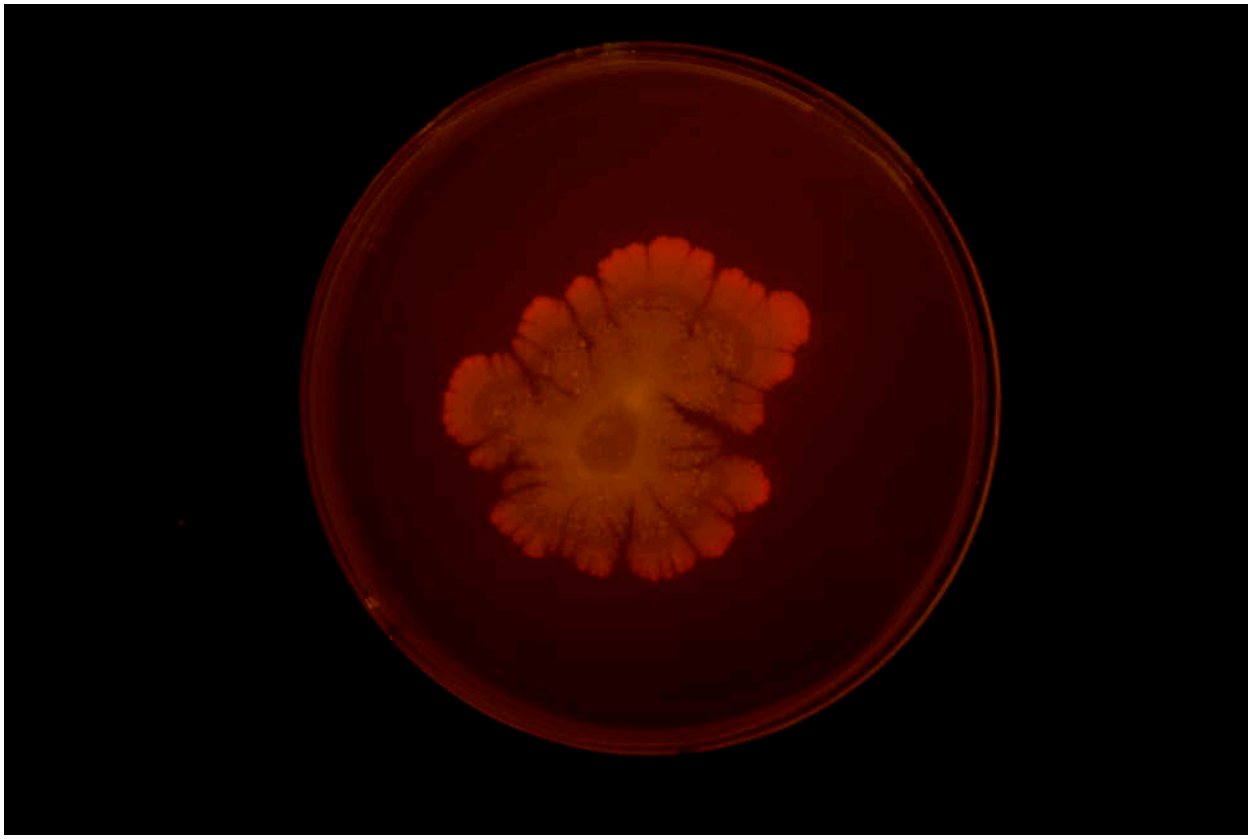

Illustration 41: Single colony growth *katE* promoter fused to an RFP construct, day 14 using swarming plates. Photo: Howard Boland.

A similar but opposite display was observed on a normal agar plate, showing a bright centre and a less fluorescent rim (Illustration 42). In spite of being opposite, both experiments were inline with the expected outcomes and likened visuals originally proposed in the research (Figure 14).

Illustration 42: Single colony growth *katE* promoter fused to an RFP construct, day 3 grown on LB-agar. Photo: Howard Boland.

Using broth, however, it was not possible to generate RFP apart from when spinning down cell pellets and as this work developed later, it would therefore not have been suitable in the work *Stress-o-stat* discussed in what follows.

## 5.7 *Stress-o-stat*

As discussed in *katE* (Section 5.6.9), continuous growth made it difficult to differentiate expression of GFP from oxidative stress and increase in cell population. Using plates introduced further complexity, since media would dry out and while liquid culture offered a better solution there was a need to bring growth under control. Fermentation methods (Section 4.15.3) were employed to setup a chemostat that could maintain constant cell population using a three-tier system - a feed, a fermenter and a deposit. It consists of tubes, vessels and pumps connected in a functional manner to maintain homeostasis. The basic set-up used two pumps, one providing fresh broth from the feed into the fermenter and a second to remove surplus culture from the fermentation surface (Figure 22). Measuring cell density at intervals and regulating the flow established equilibrium. The use of the chemostat was aimed at controlling stress parameters as light (i.e. GFP emission). Thus, changing parameters (i.e. decrease in nutrient) allowed stress to be seen as fluctuating light. For instance, when nutrients were ample less fluorescent light would be produced than during starvation.

While moving from synthetic biology to fermentation involved great deal of learning, the material and methods used deviated from *katE*. Thus, the initial purpose of the set-up was to assay the construct, however as this set-up developed it became the foundation for an installation that visually captured stress.

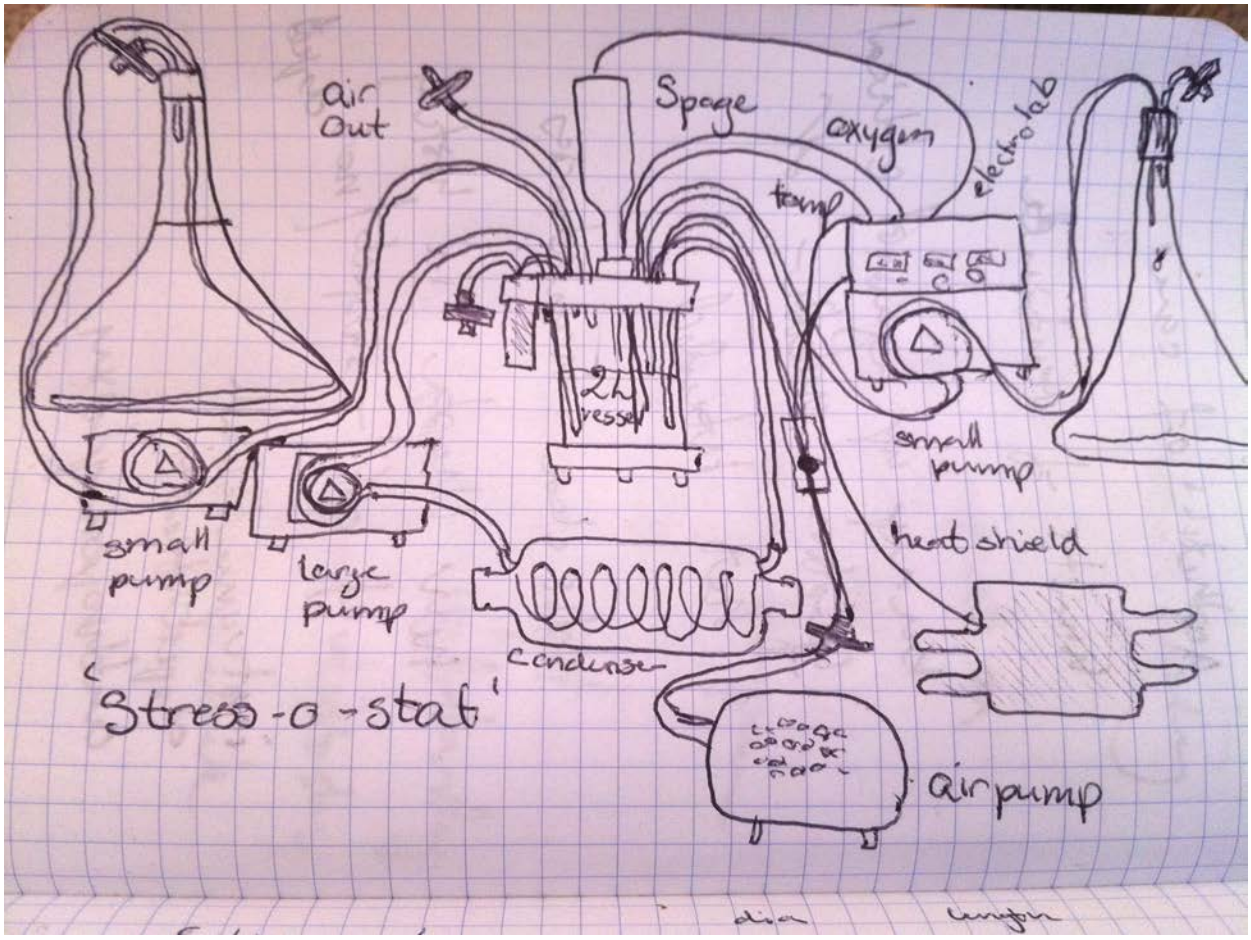


Figure 22: Proposed set-up of *Stress-o-stat*. Photo: Howard Boland.

Working with the set-up, sounds of dripping liquids and pumping mechanisms provided a sonic ambience reminiscence of medical life-support systems (i.e. ventilators, anaesthetic machines, heart-lung machines and dialysis machines). Lights, filters and a condenser were used in the installation to complete the stress-sensing device both functionally and as an experimental aesthetic of scientific parts. An external 'window' was created using a glass Graham condenser connected with tubes allowing culture from inside the fermenter to be flushed through. A blue transilluminator (i.e. Darkreader) was fixed behind the condenser and polarised orange filters blocked the blue light leaving only fluorescence emitted by proteins. As a layered process, it involves using a genetic construct that taps into oxidative stress producing fluorescent light and hosting these cells in a machine (i.e. fermentation set-up) capable of controlling and visualising these processes (Illustration 43).

During the period, parameters were slowly changed by altering the feed. Additional work would be useful to refine the system but a major step had been taken to transform genetic ideas around

*katE* to a stress monitoring system rather than growth. The name, *Stress-o-stat,* was reflective of this new phase.

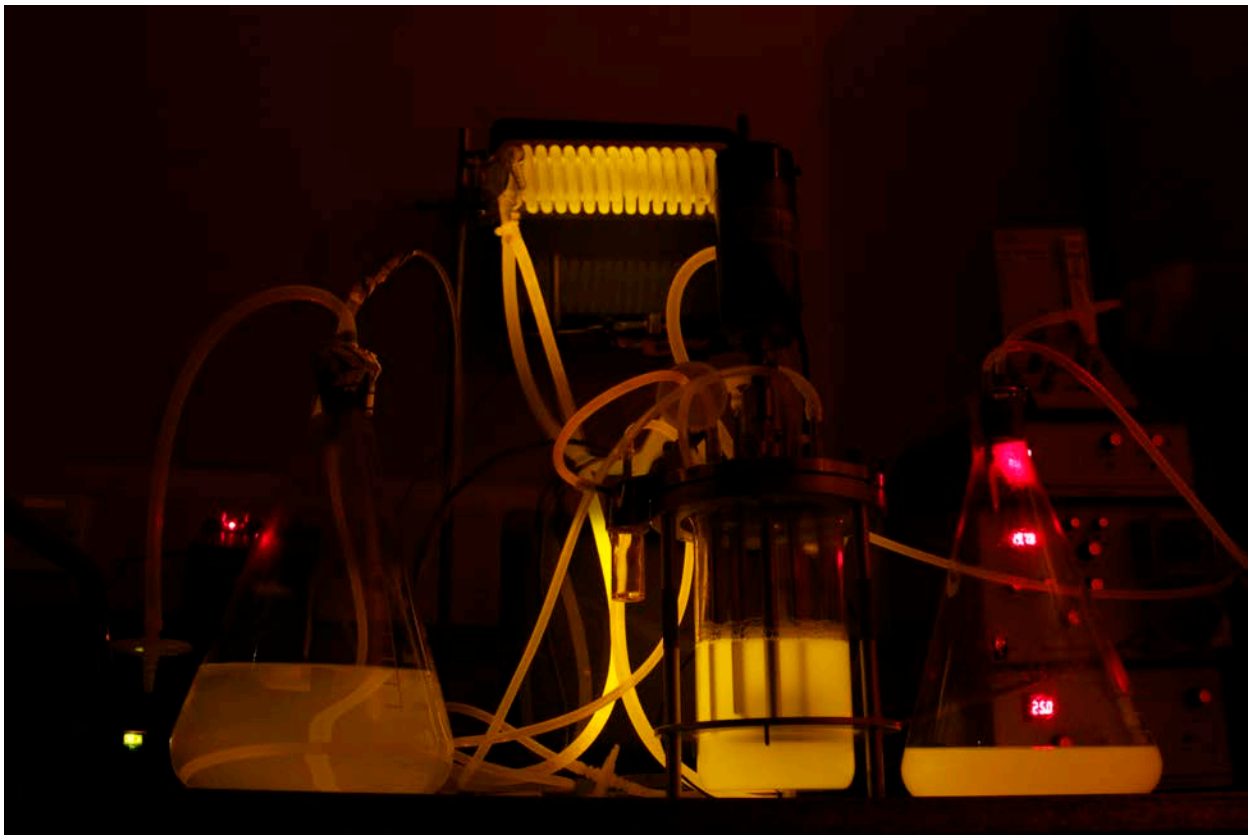

Illustration 43: Final set-up *Stress-o-stat.* Photo: Howard Boland.

*Stress-o-stat* is a living artwork that visually captures stress in bacteria as light. The work explores convergence between life and machine, where the machine becomes life-like and the bacteria, engineered through synthetic biology, machine-like.

Synthetic biology often postulates a machine-like understanding of the living (e.g. devices, chassis, reporters, circuits) describing it as programmable. Nonetheless, by deconstructing and constructing new living systems, it also enriches perspectives of life. In opting for a tool language, it may seek to ease transitions of instrumentalising life. Biology understood through machine parameters drafts life as a technology making it accessible to a wider number of practitioners across disciplines. While digital technology's movement towards simulating life-like behaviour suggests an expanded realm of the living (e.g. robotics, artificial intelligence, third order cybernetics), synthetic biology in its adaptation of engineering structures is emulating an understanding of life as machine.

Bio art has previously focused on mythical, ethical and social perspective of genetics. With synthetic biology, this ground is rapidly shifting towards a more detailed focus on constructing and developing bio matter situated on the borderline between machine and life. *Stress-o-stat* partakes in these ambiguities by employing a machine (the chemostat) to control the genetic program mediated through the living. In setting up the system, it also produces an organismic installation reminiscent of a life-support system by integration of pumps, tubes, cells, dripping liquids and light. Operating between these layers, the work unfolds and connects two interfaces that allow biological signification to emerge. So, while the interplay between synthetic biology and the control apparatus accentuates hybrid notions of life and machine (i.e. life becoming machine-like and machine life-like), as a stress-sensing device it pushes further by undressing a small portion of a biochemical universe through genetic mediation. Art in this context is no longer situated only on the outside but emerges and expands from within. The work playfully associates itself with instruments or devices such as thermometers and barometers used to guide our senses and reading of our environment. But rather than being a guide to our world, its invention deliberates ideas of extending our senses and exploring non-human worlds.

## 5.8 *Banana Bacteria*

In exploring the library to identify well-working expressions that could generate telling experiences through genetics (Section 5.6.8), one construct (BBa_ J45250) developed by the 2006 MIT iGEM team (Green et al., 2006; Shetty, 2008: 20-35) was of particular interest since it used metabolic engineering to alter the foul smell of *E. coli* by producing banana and wintergreen scents. While too often the foul smell of bacteria is one way of recognising their presence, the cause of this smell is chemical or metabolic in nature. Using synthetic biology, an alternative metabolic product could be produced by converting an alcohol (isoamyl) to acetate, an ester with a banana-like smell or more commonly known as banana oil (Illustration 44). Fascinated by how these scents confuse and prompts a rethinking of our microbial relationship, the construct was developed towards artistic outcomes that could publicly be suggestive of bacterial smells alluding to something drinkable, edible or favourable. *Banana Bacteria* investigates how synthetic biology can bring new experiences of organisms and in this case new scents.


Illustration 44: Preparation of *Banana Bacteria* in LB-broth. Photo: Howard Boland.

Using standard molecular methods (Section 4.12.1), the plasmid containing the metabolic construct was transformed into standard *E. coli* laboratory strain (XL-1 Blue). Using antibiotic selection, colonies were picked and grown in liquid LB culture before scaling up volumes (to 200 ml) and then induced with small amounts of isoamyl alcohol.

At first the experience of banana smell was confusing since the isoamyl alcohol has a faint banana scent underneath an otherwise pungent alcohol smell. Over time the banana smell became more pronounced, having a sweeter and less alcoholic odour. Using standard strains (i.e. XL-1 Blue), the natural smell blended with the banana smell producing a mixture between sweet and rotten (i.e. an overripe banana). When sharing the flask with colleagues the result was mixed, some said 'it just smells like *E. coli*', others were unclear, whilst several, including myself, thought it smelt like banana (Illustration 45).

Illustration 45: Smelling *Banana Bacteria*, an olfactory experience. Photo: Howard Boland.

As vessels for the liquid culture, the set-up used round shaped flasks (i.e. Florence flasks) mounted on a laboratory stand with a glass cap (Illustration 46). In order to harness the experience, a special indole inefficient or odourless knockout strain (YYC-912) was obtained from the University of Lusanne (Switzerland). Since the LB-broth produces a sweet caramel-like scent, a scentless growth media (M9 minimal media, Appendix I.I) was prepared using methods described in section 4.15.2.

While scientifically the construct illustrates how synthetic biology can impact the flavouring industry, its artistic use offers an olfactory awareness that both confuses and challenges our senses; the foul warning smell of bacteria is exchanged with the sweet smell of banana. In spite of speculative scenarios posed by the work towards future applications, such as how bacteria inhabiting humans could be made to produce synthetic odours that replace bad breath (e.g. with a minty fresh breath), the focus here is on the intimate experience this set-up has in terms of interacting with GMOs and enabling such access by publicly staging the work. As a paradox, the smell as an interaction provides an actual and immediate experience beyond speculation that re-negotiate ways we think of bacteria (e.g. smell of decay) as an aesthetic by extending their metabolic capability.

Illustration 46: *Banana Bacteria* final set-up with culture in Florence Flask (minimal media, knockout strain transformed with plasmid construct). Photo: Howard Boland.

## 5.9 *Tick-Tock Bacteria*

Several existing well-working genetic constructs were explored to investigate their experiential quality directly. As mentioned in the work *katE*, the motivation stemmed from initial challenges facing the molecular work. Thus, *Tick-Tock Bacteria* looked at a construct capable of generating pulsating light through a cycle involving the production and breakdown of chemical communication signals in *E. coli* described in the paper 'A synchronized quorum of genetic clocks' (Danino et al., 2010). The system generates clock-like rhythms of oscillating fluorescent waves using synthetic biology (Illustration 47).

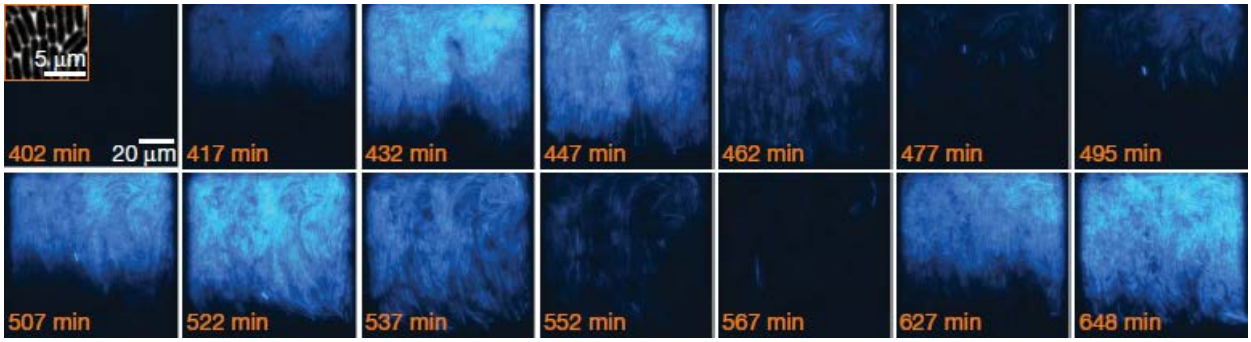


Illustration 47: Oscillating waves of bacteria (Danino et al., 2010). Image credit: Danino, Tal; Mondragon-Palomino, Octavio; Tsimring, Lev; Hasty, Jeff, 'A synchronized quorum of genetic clocks', 'Nature', vol. 463, issue no. 7279, page 305. Reproduced with permission of Nature Publishing Group.

Given their size and frequency of these waves, the aim was to first to explore the quality of the direct experience followed by possibilities of generating alternative ways of experiencing the system by minimising the need for microscopic interfaces (i.e. microscope). One such potential was to combine the system with *Suspended Lights* (Section 5.3.2) that makes use of thin wires as growth architecture to see if light waves could be produced along these. Also, it was suggested that simpler visualisation tools, such as a magnifying glass and arrays of needles, could form effective displays to explore the system in alternative ways.

Many biological systems have built-in clocks that regulate processes in timely fashions. Synthetic biology promises possibilities of building genetic devices akin to electronic devices, however, life is still contextualised in a fabric of uncertainties making application of engineering principles challenging and even simple genetic devices are fraught with complex interactions and many (if not most) yet to be understood. Devices that emerge with some level of predictability may come to have an enormous impact on biotechnology.

The authors (Jeff Hasty and Tal Danino) provided the genetic construct (bacteria transformed with the plasmid TDSQ1). Despite the material being damaged during transport (Illustration 48) it could be salvaged and a colony was transferred to fresh plates with selective antibiotics (e.g. Ampicillin and Kanamycin). Using fluorescent microscopy the culture confirmed the presence of GFP.

Illustration 48: Plates upon arrival. Photo: Howard Boland.

Visualising the oscillation required a slide UV-embossed with micron channels (approx. 200 μm x 10 μm) to section off bacteria population but since this equipment was unavailable, initial attempts used liquid separation on slides by locating sections where bacteria had become compartmentalised in small channels (Illustration 49).

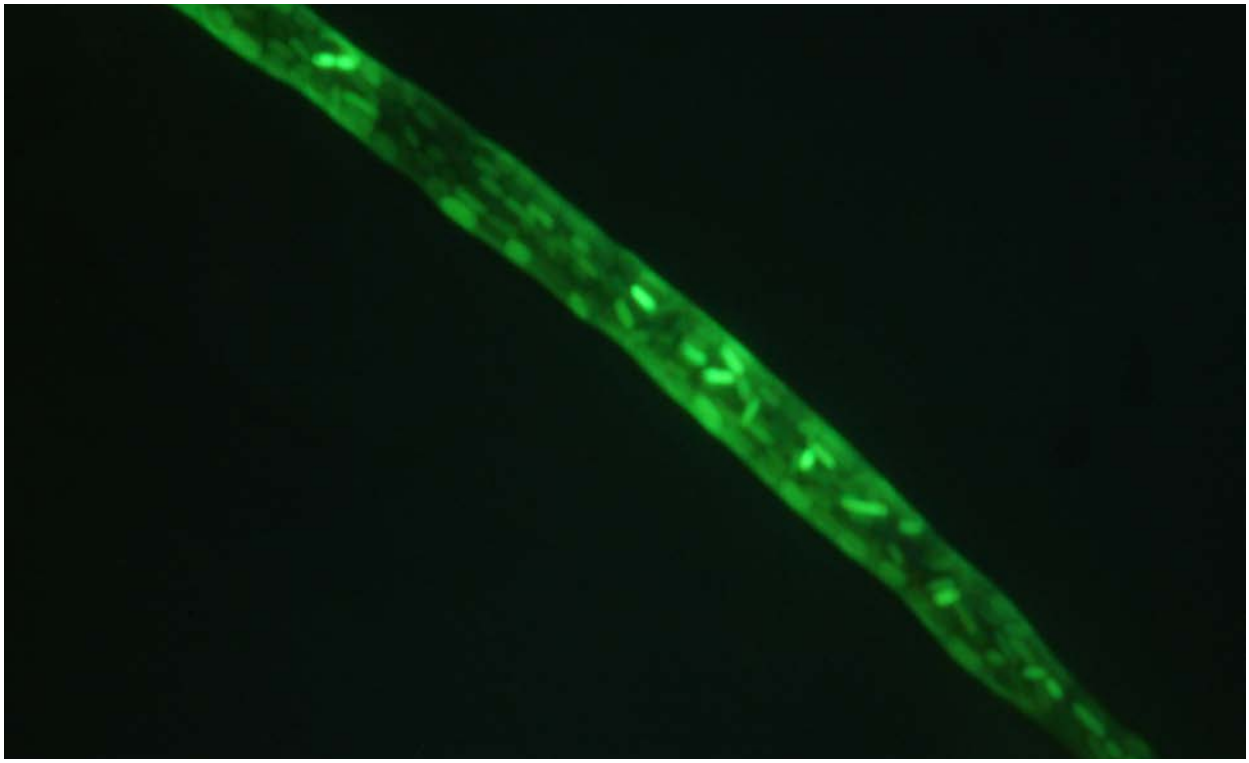

Illustration 49: Compartmentalised channel of bacteria. Photo: Howard Boland.

An immediate problem during microscopy observation was the fading of fluorescence making it difficult to differentiate between oscillating wave and a common phenomenon known as photobleaching causing destruction to the light emitting part of GFP (Herman et al., 2006).

According to the circuit description (Danino et al., 2010), the system forms from a single cell division in a cornered off section of a micron channel to maintain constant density. The genetic circuit is made up of three identical modules that drive the production of GFP, a quorum-sensing molecule (N-Acyl homoserine lactones or AHL) and an enzyme that degrades the signalling molecule. The regulation is such that the production of the signalling molecule (AHL) diffuse into neighbouring cells and activate transcription that switches on (1) GFP, (2) extracellular signalling molecules (AHL) and (3) an enzyme breaking down signalling molecules (AHL) remaining in the intracellular space. This regulation produces a signalling thrust moving from cell to cell and can be seen as a wave. In each cell the transcription (i.e. production of GFP etc.) phases out with the loss of signal. Since the signalling molecule exist naturally in *E. coli*, once the system has become inactivated it will again burst and so forth in an oscillating manner. After a population is established oscillation produces waves of colour at an interval of one hour. The length of the wave extends to about 100 μm or the average thickness of a hair strand, thus to visualise, a microscope with time-lapse facilities is needed.

At the time of observations, the camera used produced shutter movements making it impossible to keep a constant focus area. To overcome this, two-carbon slates laser-cut with a thin channel could be used to form a microfluidic system (i.e. a slide with tubular channels). Further, this would provide positional and population control under the microscope. However, this would still not overcome the problem of photobleaching and problematises the issue of interfaces. Further, the work would also require time-lapse to capture the relatively slow motion of the oscillation. Attempts to cut glass did not produce viable results and while the use of strings was promising the issue of photobleaching remained unresolved.

## 5.10 *Bacterial Light Sensor*

After successfully assembling the *katE* promoter into the reporting construct to build a stress-sensing device (Section 5.6), a subsequent project was proposed involving a genetic light-sensing system (Figure 23) in bacteria capable of producing a protein (e.g. fluorescence or pigment) when exposed to light (red light). The aim was to develop an interactive light sensing sculpture using an agar-based mould with lawn of bacteria and applying light. Funding was granted from the Society of General Microbiology for a life-science student (summer scholarship) to work on

this project and learn methods of synthetic biology, as described in section 4.12 & 4.14. The work relied on extending a multi-component light-sensing system (i.e. BBa_M30109), at the time treated as a 'black box', however, this did not behave as expected and attempts made to re-assemble prompted the need to grasp these processes and what follows is therefore subject to a more technical account.

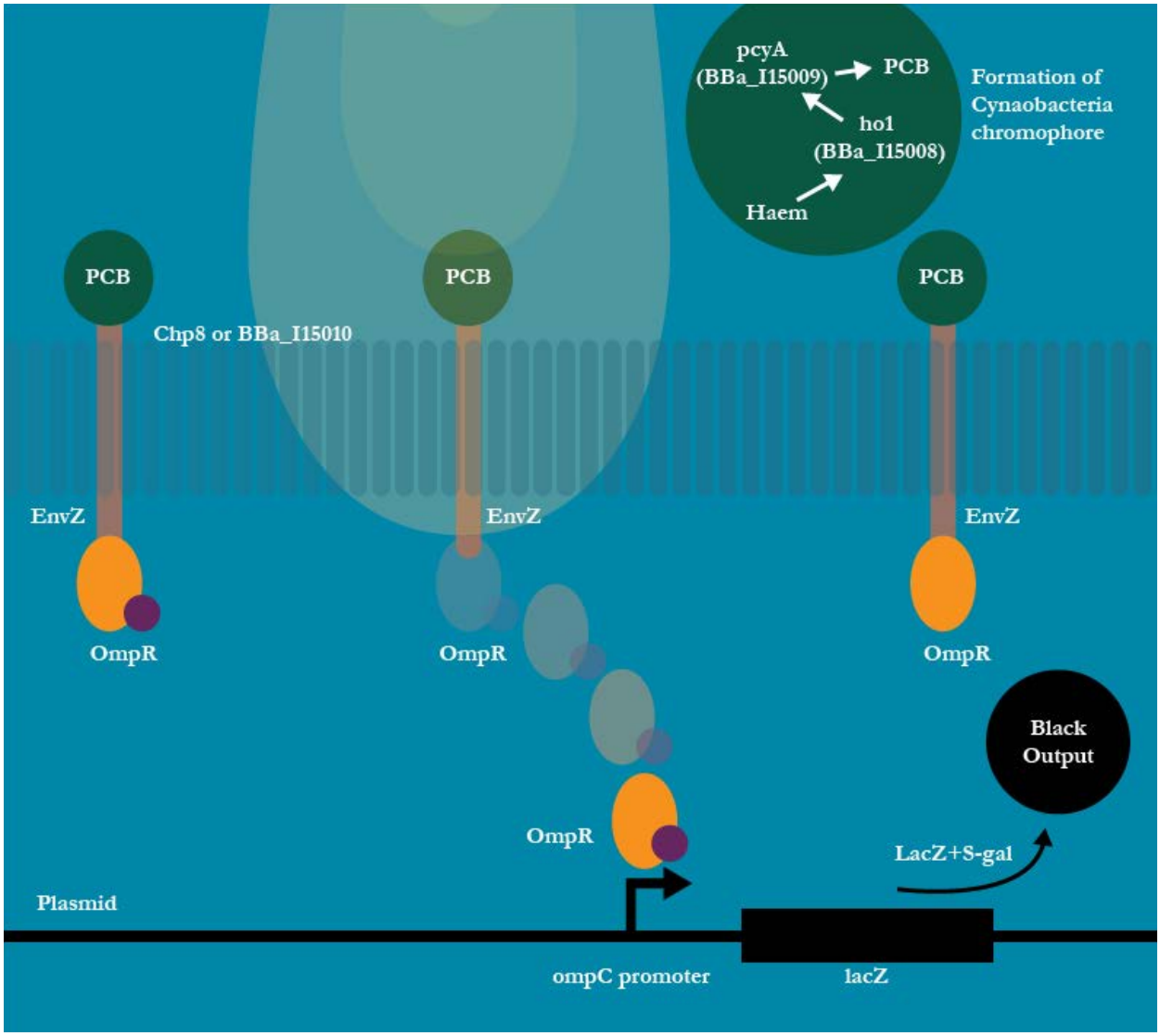


Figure 23: Adapted diagram of interactions taking place in the light sensor (Levskaya et al., 2005). The chimeric protein consists of a fusion between EnvZ/Chp1 and chromophore PCB produced synthetically in *E. coli*. A knockout strain (where certain genes have been removed from the genome) was used to remove the production of histidine kinase porins (*envZ*) thereby enabling only light-sensing proteins to phosphorylate OmpR in the presence of light. A plasmid construct with an *ompC* promoter fused to a colour pigment and activated by phosphorylate OmpR allows a colour to be generated in response to light. Illustration: Howard Boland.

*E. coli* do not naturally harbour any known light-sensing system but several attempts have been made to introduce this capability using a genetic system. *Bacterial Light Sensor* suggested employing an existing system developed through synthetic biology and described in the paper 'Engineering *Escherichia coli* to see light' (Levskaya et al., 2005). The light-sensing part (red light

sensing) is a chimeric fusion protein (Cph1) extracted from light harvesting cyanobacteria (*Synechocystis* sp. PCC6803) and fused with the tail-end of a two-component osmosis regulator membrane protein (histidine kinase or EnvZ) found in *E. coli* (see Figure 23). In the study, a multicomponent system is needed since *E. coli* does not naturally produce all required parts. For instance, to produce the cyanobacteria chromophore phycocyanobilin (PCB), first Haem (an iron-binding group) is oxidised to biliverdin IXalpha (BV), a greenish pigment, using the enzyme heme oxygenase produced by the gene *ho1* (or BBa_15008) which in turn can be converted to phycocyanobilin using the enzyme phycocyanobilin:ferredoxin oxidoreductase produced by the gene *phyA* (or BBa_15009), to finally form PCB. A strong chimeric light-sensing protein (Cph1/EnvZ) Cph8 (or BBa_I15010) has crossover points to link PCB to EnvZ and make up the light sensor. The system is non-trivial and also needed a special knockout strain to be directed to light only (and not interfere with osmolarity-sensing).

The system was identified as part of locating well-working genetic constructs and has been celebrated as a key accomplishment in synthetic biology (Shetty, 2006; Jerala, 2009). Importantly, it has also been generated using standardised parts (e.g. BBa_I15010, BBa_I15009, BBa_I15008) and a complete commercially synthesised construct was available through the library (BBa_M30109). Preliminary research suggested that the construct could be extended to include a fluorescent reporter to produce images. To induce expression, authors originally used silhouette filters and a bright red light source exposed onto a lawn of bacteria generating a black colour where cells had been exposed to light[106] (Illustration 50).


Illustration 50: Example of light sensor (also called bio-photolitography) in action (Levskaya et al., 2005). Permission to reproduce this image has been kindly granted by Anselm Levskaya.

[106] A similar process of exposing light using filters onto grass has also been done by Harvey and Ackroyd for instance in their work *Mother and Child* (Section 2.4).

Initially the work suggested using a collagen scaffold that could be moulded in three-dimensions to add imprints by shining light. This aspect was kept open-ended as expressions, accuracy and time-latency were unclear. Since the system was already used as a teaching tool (Kuldell, 2007: 3-4), it was thought solid.

The first task was to develop a construct by combining a promoter (ompC promoter or BBa_R0082), activated by osmolarity signalling molecules (phosphorylated OmpR), with a GFP reporter construct (BBa_E0840). During osmosis regulation (a continuous process), it was expected that phosphorylated OmpR would be constitutively expressing GFP. This was generated using idempotent assembly (Section 4.14.2) and concurred with observation of GFP (Illustration 51).

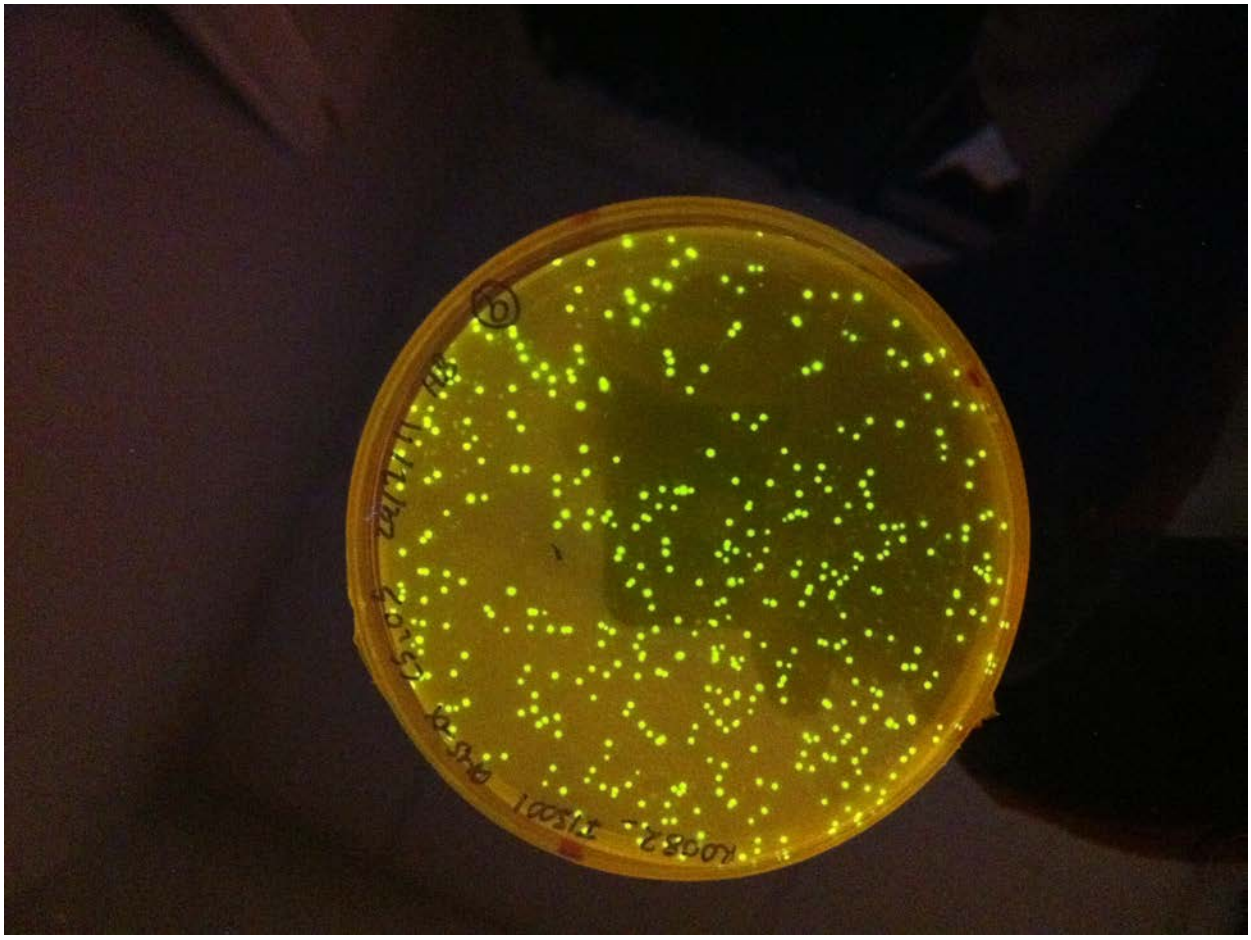

Illustration 51: *omp*R promoter fused with *gfp* reporter construct. Photo: Howard Boland.

The second part involved extracting the commercially synthesised light-sensor (BBa_M30109) with the aim of incorporating it with the osmolarity-sensing fluorescent construct. The aim was to have the light-sensor generate phosphorylate OmpR rather than the natural EnvZ (i.e.

osmosis-sensing trans-membrane protein) in order to have GFP expression during light exposure, thus the strain also needed to have a knockout of this gene (e.g. ΔenvZ).

### 5.10.1 The BioBrick™ library and its reliability

Using the Spring 2010 distribution BioBrick™ library, the synthesised part (BBa_M30109, ~3kb) was available but showed unstable behaviour during cloning work: transformation produced a low colony count, colonies grew poorly in broth and purification gave insufficient yield to be extracted and cut. Attempts to amplify the region using PCR showed either blurred or missing bands on agarose gels. After several attempts the author of the submitted BioBrick™ (Natalie Kuldell, MIT) was contacted who responded that the part was a "train-wreck" (see below) and never really worked:

> *I regret to say that the M30109 part is a train-wreck, and I don't think it was ever working. I ordered it synthesized for a class I was teaching several years ago, but the part did not arrive in time to use in my class (perhaps due to some instability), and when I sent the DNA to the registry it was untested. I think a number of teams have tried to use this part without success. I regret that the best path forward seems to be one that does not include M30109.* (Email correspondence, Natalie Kuldell, 24/06/2011)

This was a major setback with no immediate solution. To re-route the project we decided to reconstruct the part (i.e. BBa_M30109) using existing sub-components from the library (e.g. BBa_I15010, BBa_15009, BBa_15008) and apart from generating the composite, it was also thought a useful contribution to the community. Simultaneously, correspondence with original authors was initiated (e.g. Christopher Voigt, J. Clark Lagarias and Jeff Tabor) to obtain working material based on the paper rather than the library. Authors were accommodating in providing material, however, one component (i.e. pPLPCB used to produce the chromophore, PCB) was governed by material transfer agreement (MTA) making the processes tedious (Section 4.10). The remaining components could be shared and of particular importance were the knockout strains. One collaborator (Eric Davidson) worked at Imperial College (London) allowing a local exchange. Due to seasonal circumstances (e.g. holiday and change of administration staff) there was a substantial delay in obtaining material and reconstructing the system seemed a sensible solution.

### 5.10.2 Multipart assembly

The assembly process was significant and involved a multipart system with a total of 12 subparts, thus the cloning exercise became the major activity for the work. The chimeric fusion part

(BBa_I15010) faced similar problems as the synthetic construct (BBa_M30109) in terms of extraction. As discussed in the previous chapter (Section 4.14.3), the process would have benefitted from using multicomponent assembly methods rather than idempotent assembly (Section 4.14.2).

The assembly process was aimed at first building three composites by extending BBa_I15008, BBa_I15009 and BBa_I15010 with genetic components needed for regulated expression of these genes (e.g. ribosome-binding sites, terminators and promoter parts for gene transcription). With these composites in place they would be assembled to a final construct.

Following the working schema in Figure 8, colony PCRs were used to check for inserts throughout the assembly in an iterative manner until a correct size was verified using agarose gels and UV-documentation. After each assembly steps, digestions were followed by ligation and transformation to generate subsequent parts until a full assembly was reached. The work used gel verification only and a more robust (but more expensive) method would have involved sequencing each step. The products were only sequenced upon final assembly. Unfortunately, the final sequence showed discrepancies.

### 5.10.3 New material

Most of the additional material arrived after the major assembly exercise and included two knockout strains (i.e. RU1012 [$\Phi P_{ompC}$-*lacZ*, Δ*envZ*:$Kan^R$] and JT2 [RU1012 <$\Delta P_{ompC}$-*lacZ*:$Kan^R$>]) with anti-sensing for osmosis by removal for *envZ* genes. A multi-chromatic sensor (pJT12) developed by the group in a later work (Tabor et al., 2011) and capable of sensing two different lights (i.e. red and green) was also obtained but still missing was the chromophore construct.

Using the knockout strains, competent cells were prepared and tested with the previously developed $P_{ompC}$-GFP reporting construct (Illustration 51). Confusingly, this still produced GFP indicating that the phosphorylated OmpR was still being generated. Given this result, the project was placed on hold until the material was studied. Further findings showed several attempts by iGEM teams to develop light-sensing devices were fraught with problems (iGEM Edinburgh, 2010; iGEM Tokyo, 2010; iGEM China, 2012). In particular, the assembly of the chromophore did not work using parts from the library as a result it would not have be possible to proceed in any case until such parts became available.

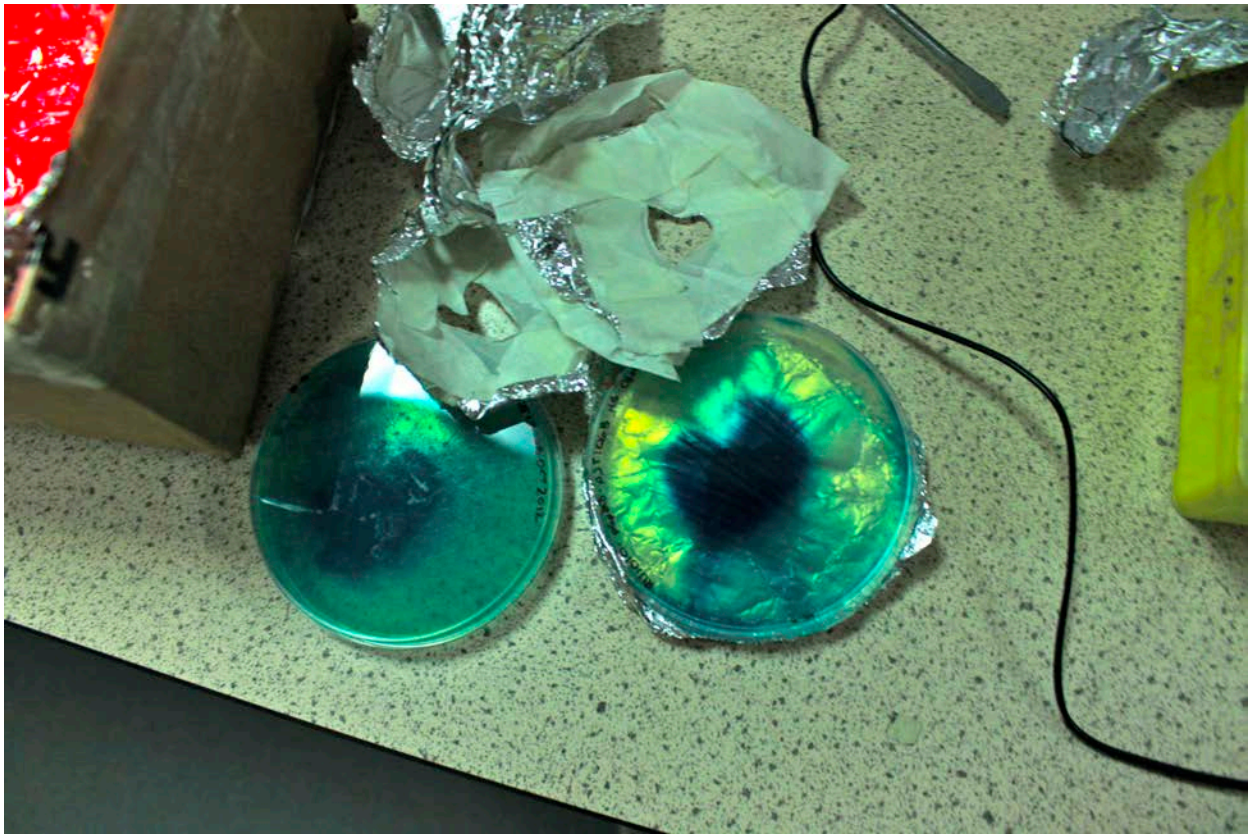

Illustration 52: Final attempt to produce an operational light sensing system. Plates were coated with a lawn of bacteria and incubated overnight. A second layer of IPTG was then added before wrapping plates in foil with a cut out silhouette of a heart. The plates were placed in a red-light box for 2 hours and then taken out for photography. Photo: Howard Boland.

As with some of the works developed in the practice it was not possible to achieve the final outcome within the research timeframe, still these opened avenues to be explored in future research. From the outset of this project it suggested that the material and mechanism could be implemented with a level of ease that ignored many of the complexities dealt with by the authors. As an artist working with synthetic biology independently there are clear advantages of using 'black-boxes' to reduce intricate details. Synthetic biology in its use of interchangeable parts and devices aligns itself with approaches in electronics and computational engineering whereby using these parts only requires a high-level understanding that effectively 'black-boxes' inner workings. The advantage is far reaching since it allows a layering of language. Borrowing from computational history it involves a movement from the machine layer (i.e. electronics, binary and assembly code) to high-level languages independent of the hardware. However, as the *Bacterial Light Sensor* exemplifies, it needed to become engaged on an intricate level with the abstract processes and disparate material and while enriching understandings, it led into very complicated avenues with material dependencies that in the end took too long to achieve outcomes. In such case, the independent practice stands to fail achieving goals within timeframes (4-5 months). As will also be discussed in what follows (Section 5.14), there is a need for a level of physical

mobility when working with new and often challenging material, and tackling such challenges may require travelling to specialist institutions to undertake preliminary work.

### 5.11 *Living Mirror*

As discussed, although not all experiments and projects materialised, even so they helped develop an understanding of specific material that may be used in future works or lead to other works. In what follows, the experiments made over three separate periods to develop the work *Living Mirror* are described, which aimed to produce a living interactive display and visualisation platform by combining magnetic bacteria, electronics and programmatic photographic manipulation (Illustration 53).

Illustration 53: *Living Mirror*, conceptual set-up. Photo: Howard Boland.

The foundation of the work rested on the use of microbiology and growing highly specialised magnetotactic bacteria (MTB)[107] that could be controlled using a custom-made magnetic grid to

[107] First discovered in 1975 by Richard Blackmore (Blakemore, 1975).

generate visuals. Initial discussions (with a colleague, Anatoliy Markiv) proposed tethering the magnetic property to microwaves allowing interaction with mobile phones and by developing a genetic construct that could express a light or a colour based on these signals. In spite of being a fascinating idea, it involved several unknown pathways and a more manageable route seemed to be to simply use the magnetic property directly to generate images. Given a digital photograph as a bitmap, reduced to a series of blocks consisting of darker and lighter greys, we could represent this image as a numerical array or a grid of values from one to zero. Using an electromagnetic grid of the same resolution (i.e. same number of points) these values could be converted to magnetic forces so as to pull or release bacteria. The electromagnetic grid would be positioned inside a liquid culture in a protective coating. Further, by applying the transformation using a web camera with live footage, it was imagined that the liquid culture could produce a mirror like reproduction of images, hence the name *Living Mirror*. A freeze frame (i.e. a still image from web camera) could also be explored where the three-dimensional cloud-like mass of bacteria growing out from the image slowly distorts it (Figure 24).

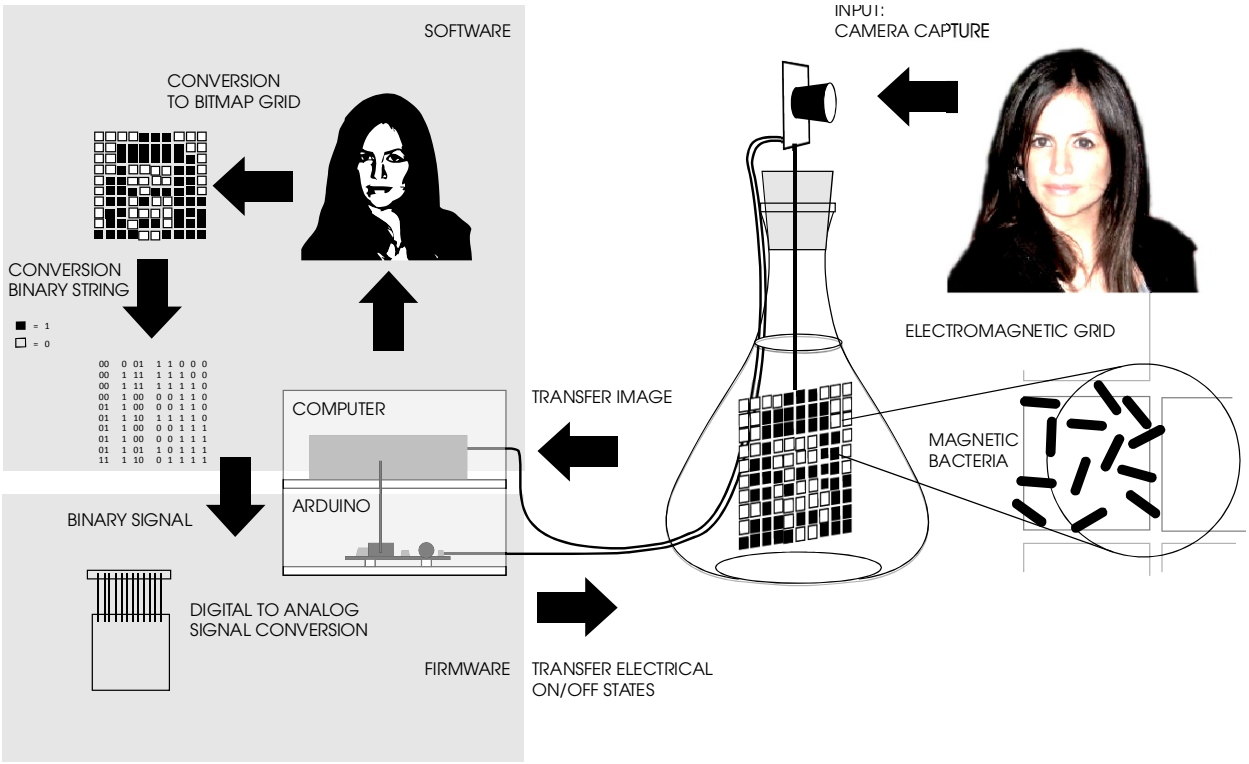


Figure 24: Outline of *Living Mirror* showing the integrated set-up. Illustration: Howard Boland.

Initially (February 2011), no genetic capacities for magnetotactic potentials existed in the library of standardised parts and despite claims of such later emergence (2012 distribution) it remains uncertain if this property is transferrable to *E. coli*. A literature search revealed several

magnetotactic species[108] and identified institutions working with these strains to obtain samples. Most of the research was clustered around two groups, Matsunaga Laboratory (Tokyo University of Agriculture and Technology) and the Magnetotactic working group (Ludwig-Maximilians-Universität) led by Dirk Schüler. While communication with the Japanese group was complicated due to language barriers, the German group provided very clear information on what species to use and how to procure this from a commercial company (i.e. Deutsche Sammlung von Mikroorganismen und Zellkulturen GmbH (DSMZ), Germany).

Following Schüler's advice, a sample of the wild-type species, *Magnetospirillium gryphiswaldense* (MSR-1), was obtained from DSMZ (Illustration 54).


Illustration 54: Ampule with *Magnetospirillium gryphiswaldense* (DSMZ). Photo: Howard Boland.

Notably, Schüler isolated this freshwater pond species himself and spent his career studying these organisms (Schüler and Baeuerlein, 1997: 648; Schüler, 2002: 209). In fact, these organisms had already called my attention as part of a literature search in an earlier art project *The Martian Rose* (Boland and Cinti, 2007/2009), where magnetite particles of a similar morphology had been found as imprints in the meteorite ALH 84001 (McKay et al., 1996; Gilmour and Sephton, 2004:

[108] Magnetospirillum magnetotacticum strain MS-1; Magnetospirillum magneticum strain AMB-1; Magnetospirillum gryphiswaldense; and Magnetospirillum bellicus.

114-119) suggesting possible extra-terrestrial bacteria-type organisms. However, I had no working knowledge of the species and advice received suggested that cultivating these organisms would be difficult:

> *Thanks for your interesting email. As for your questions, if you are just interested in the magnetic wild type, the easiest way to obtain it will be from the German strain collection http://www.dsmz.de/. It can be purchased there for not much money and the staff will handle all shipping and paperwork. Cultivating and handling the bacteria is a little more demanding than for example E. coli, as the organism is a microaerophile which requires some specific microoxic technology, which however, has been all described (see for example, the attached paper by Heyen et al). The same is true for genetic manipulation (e. g. for transformation with GFP constructs), which can be done by conjugation of broad host range plasmids.*
>
> *The suggested magnetic alignment of bacteria certainly would not only be of artistic interest, but also for the generation of microscopic and nanoscopic magnetic structures or arrays with potential for applications.* (Email correspondence, Schüler, received 02/11/2011)

As pointed out in the email correspondence, working with this species would involve a new set of methods that my laboratory had no specialist expertise in using. Initial attempts did not follow media-specific advice and used various rich growth media (e.g. LB-agar, iron agar, klingen agar, blood agar) available in the laboratory, unsurprisingly this resulted in no growth.

By keeping in line with suggested growth methods (Heyen and Schüler, 2003), preparation of Flask Standard Media (FSM), a semi-defined media, as both solid (agar plates) and liquid media was undertaken. To cultivate this media, samples were streaked on plates, placed in an anaerobic jar containing satchels that remove (or purge) oxygen, and incubated at ~27ºC. As opposed to *E. coli* growth time of 1 day, the estimated period to produce either colonies or slightly turbid culture was expected to be around 1-2 weeks, but after two weeks no visible colonies or signs of turbidity could be seen (Illustration 55).

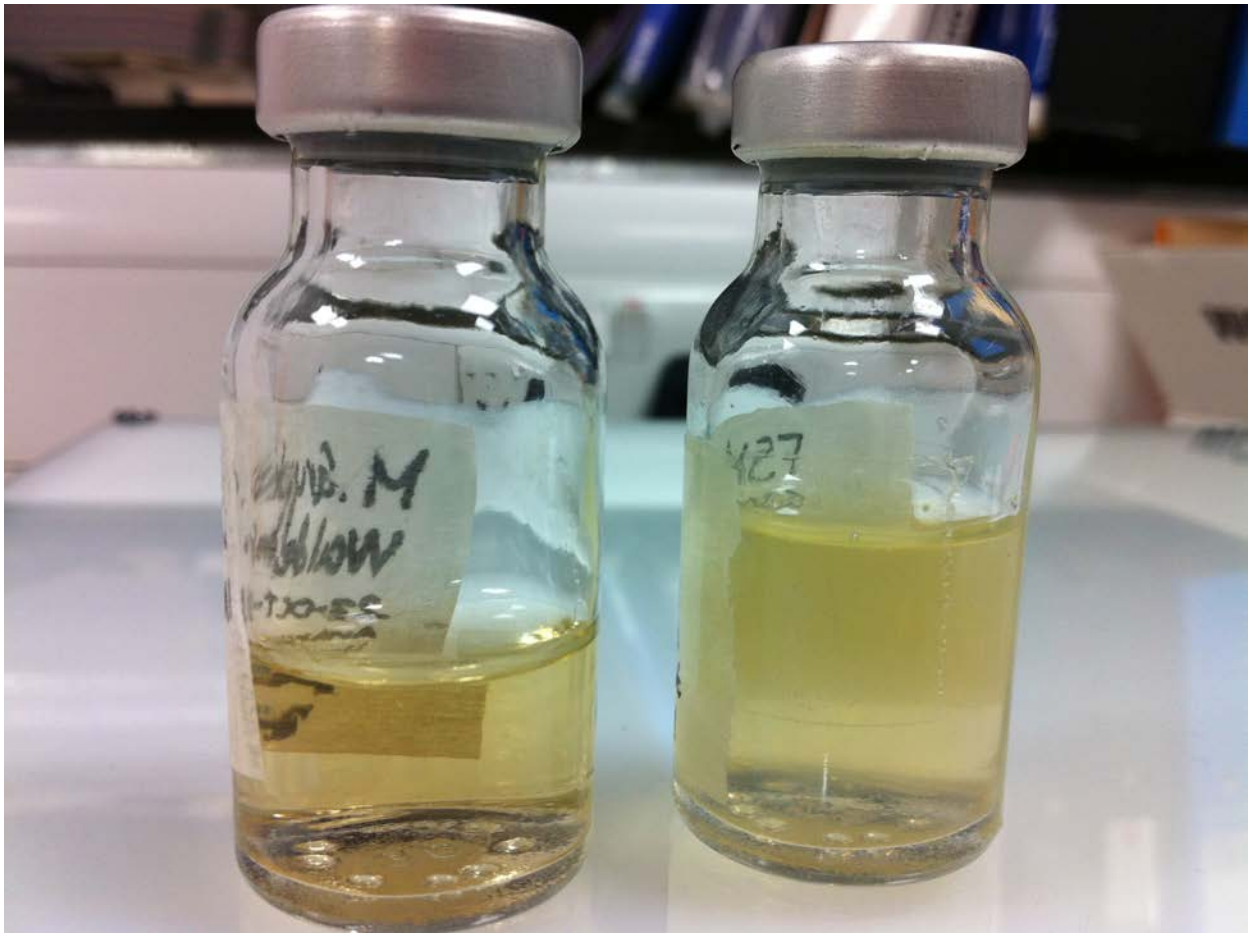

Illustration 55: Sealed vials containing FSM media and inoculated with 10% culture showed no visible growth after 2 weeks of incubation. Photo: Howard Boland.

Microscopy studies to check viability (e.g. observation of swimming) showed low activity. Attempts using liquid broth were unsuccessful and at times produced contamination (e.g. *streptococcus* – commonly found on human skin) confirmed by Gram staining undertaken to identify specific types of bacteria under a microscope (Section 4.16.3). Given the slow growth of magnetotactic bacteria, faster growing organisms (e.g. the aforementioned *streptococcus*) readily outcompete their growth. By sealing the flask and allowing minimal headspace between media and lid (e.g. 10-5%), a low-oxygen environment (microaerophilic) was produced. Experiments have shown that the orientation of these cells is such that if a magnet is held close to these cells with the north pole pointing towards them they translocate towards the magnet.

> *The preferred motility direction found in natural populations of magnetotactic bacteria is northward in the geomagnetic field in the northern hemisphere, whereas it is southward in the southern hemisphere. Because of the inclination of the geomagnetic field, migration in these preferred directions would cause cells in both hemispheres to swim downward.* (Schüler, 1999: 81)

Thus, it has been suggested that magnetotaxis allow these organisms to use geomagnetic fields as guidance and swim to an optimal position in the microaerophilic gradient.

### 5.11.1 Anaerobic and microaerophilic attempts

A second attempt at growth was undertaken after learning anaerobic cultivation methods in the work *Transient Images* (Section 4.15.2 and 5.14) that involved getting accustomed to preparing semi-defined and defined media (e.g. FSM, DSM380 [*Magnetospirillium* Media]). However, in spite of significant attempts of varying media, conditions and carbon, the outcomes showed no significant growth or turbidity.

Discussions with one colleague, whose attempts to grow soil-based bacteria (i.e. *Geobacter*) using similar methods (and media) had been unsuccessful, suggested a need to visit specific institutions to acquire specialist skillsets. Further, invested time required for obtaining such skills (e.g. growing fastidious organisms) is significant enough to consider establishing collaboration with experts.

### 5.11.2 Genetic solutions to magnetotacticity

Originally, a genetically transferable solution was sought for the implementation of magnetotaxis in fast growing systems (e.g. *E. coli*). The magnetic property in MTB emerges from a biologically controlled ability of bio-mineralising magnetite (Mann, 1988), it involves (1) the production of a storage vesicle (magnetosome), (2) creation of a chain-formation enabling the uptake of iron particles and (3) storing these in an organised manner inside the cells. However, a genetic understanding of magnetosome formation has been hampered by challenges of cultivation and molecular methods in spite of efforts (Bazylinski and Frankel, 2003; Schultheiss and Schüler, 2003: 237). While the genetic constitution is not completely understood, an operon-like gene-cluster has been identified (Groenberg et al., 2001; Grunberg et al., 2004) and shows that some of these properties are transferable in *E. coli*[109]. A specific region of the genome known as the 'magnetosome island' is considered to contain all gene functions involved in magnetosome formation (Ullrich et al., 2005: 7181).

> …*some genes from* Magnetospirillum magnetotacticum *can be functionally expressed in* Escherichia coli *and that the transcriptional and translational elements of the two microorganisms are compatible.* (Bazylinski and Frankel, 2003)

[109] For example, the formation of magnetite crystals (Arakaki et al., 2003).

Developments coinciding with my growth attempts suggested emerging potentials of cloning these genes into *E. coli*. Of note, the winning iGEM team of 2011 from the University of Washington extrapolated each of the known functional genes and assembled these in *E. coli*.

However, to date, a functioning transferable genetic solution has not been shown, in spite of a video produced by the team seemingly demonstrating this ability (washingtonigem11, 2011). The latter was misleading in suggesting that a solution was available through synthetic biology to realise the proposed art installation. Based on correspondence with the team, it was established that the culture shown in the video was a not the magnetotactic *E. coli* but a commercial magnetotactic species *AMB-1* (similar to *Magnetospirillium gryphiswaldense*). Further, the operon had been cloned into three large fragments but had not been assembled as a complete circuit and it was uncertain if this would work.

> *I'm afraid you might be overestimating how far we got with this project. The movie where we show […] bacteria responding to an external magnet is* AMB-1 Magnetospirillium magneticum *and is just an aliquot of that strain that we received from the Komelii lab at Berkeley…We were trying like […] you said to make growing magnetosomes easier by porting it to* E. coli *but ultimately we ran out of time. We did turn some of the essential parts of the operon into Gibson Biobrick form and characterize them but we never were able to completely assemble the complete operon in* E. coli. *We were getting pretty close though.* (Email correspondence, Michael Brasino, University of Washington 2011 iGEM)

With so many uncertainties and potentials at hand, it was exciting but disappointing not to get further with this work during the study. However, what we see in both *Bacterial Light Sensor* and *Living Mirror* are attempts to reach into more complex material possibilities and how this also leads into increasingly more intricate challenges in terms of manipulation (whether growth or genetics). Interestingly, it was possible to do some brief studies of magnetic interaction in bacteria using magnetic nanoparticles (i.e. fluidMAG-D 70 mg/ml, Chemicell) obtained from Cinti who had worked with these artistically in plants (Cinti, 2011c). While this involved using a microscope as an interface, it was nonetheless fascinating to observe the interaction on the level of individual cells. In what follows, I will briefly describe the experiment and its outcomes.

## 5.12 *Bacterial Compass*

*Bacterial Compass* combined several ideas developed during the research and involved introducing magnetic nanoparticles in bacteria (*E. coli*). As with *Living Mirror* it was thought that having

magnetically actuated particles embedded in cells would allow them to be moved using an external magnet. As an experiment, it was not clear how the cells would react but the outcome showed a surprisingly compass-like swinging behaviour and is contextualised as a method to control and interact with these organisms. Compass-like bacteria have been described in scientific studies before (Beck and Frese, 2001: 35-38) but this experiment captures rotational behaviour where each cell (with rod-like structure) can be manipulated.

The study was undertaken using a microscope and initial observations showed significant visual noise due to the granularity (dark coating) of these particles and the small size of *E. coli*.

To improve visualisation, a stock solution *E. coli* transformed with an RFP construct (Section 5.6.10) was mixed with magnetic nanoparticles in a ratio 2:1. A slide was prepared and a fluorescent microscope (10x100) with a strong external magnet moved and rotated around the slide (Illustration 56).

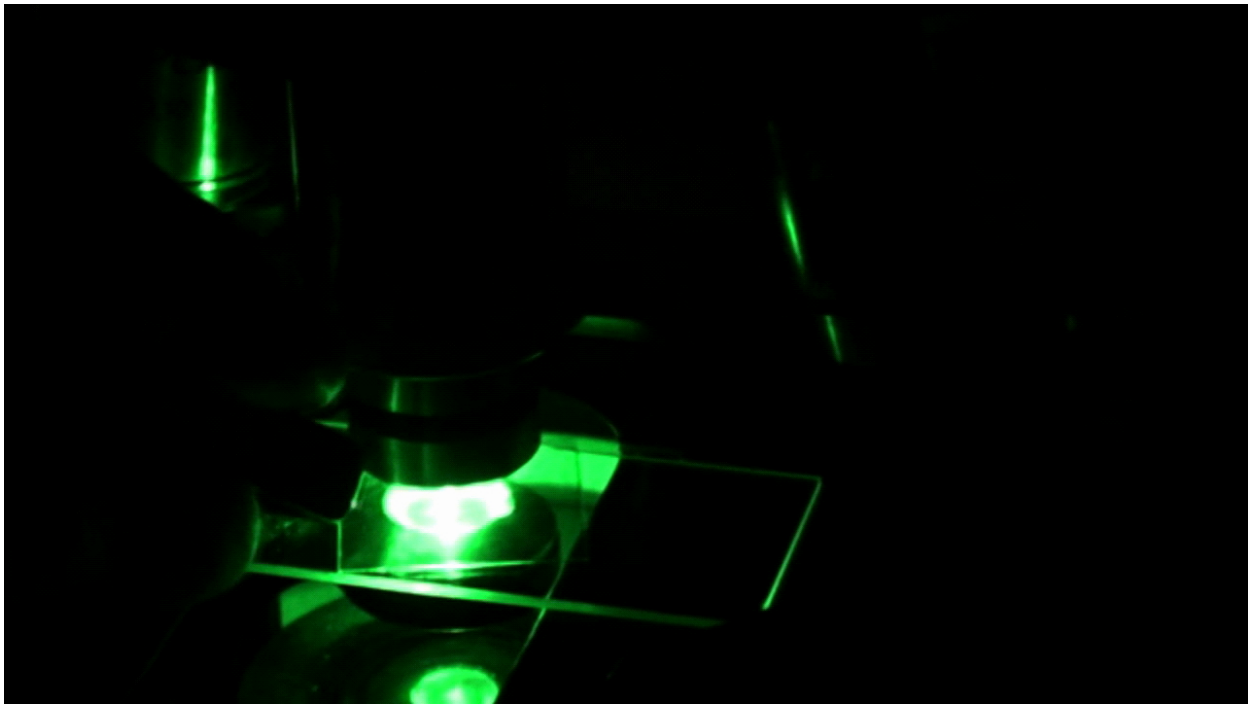

Illustration 56: Manipulation of bacteria using external magnet around slide. Photo: Howard Boland.

In contrast to *Living Mirror* that aimed at using naturally magnetotactic bacteria with internalised magnetite, it remains to be determined if these bacteria engulf and internalise these nanoparticles. Brownian fuzziness seen under white light indicated that these nanoparticles formed a uniform field around the cells that, much like a river, would hold and push the rod-like cellular body of *E. coli* in the direction of least resistance, that is orienting the poles to be aligned with the magnetic field or direction of surrounding particles. Furthermore, individual cells could

be held in static position and rotated by the magnet. This was surprising since it was expected that the cells would move along with the particles (Illustration 57).

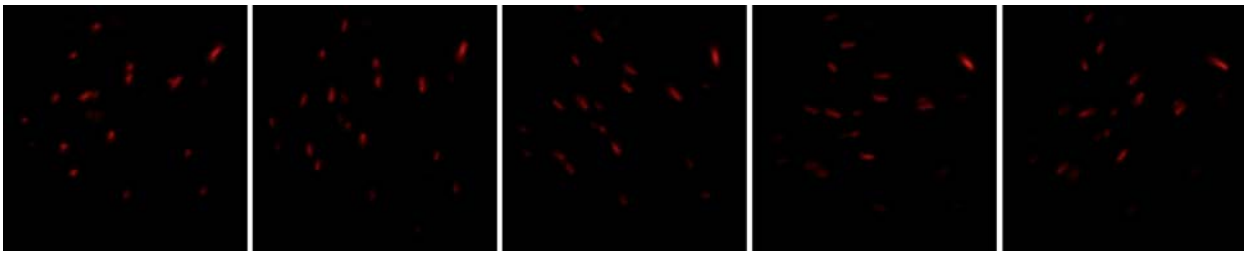

Illustration 57: *Bacteria Compass*, series of five frames from microscope video showing *E. coli* responding to a magnetic field using an external magnet. Photo: Howard Boland.

The experiment did not lead to a specific artwork but informed the research of real-time interactive potentials that are particularly difficult to produce in bacterial systems. As a real-time interactive experiment, it overcomes some of the challenges of time imposed by genetics making many of these works processes-based, however, what remains is the interface (e.g. microscope). Instead, to overcome challenges of time, the use of mediation was explored through time-lapse and this involved building a time-lapse facility.

### 5.13 *Growth Chamber*

Exhibiting bio media posed different challenges to exhibiting traditional media, because, being living material, it grows and dies (Section 3.1.2). Biological processes are often not immediate to the observer (i.e. growth) and the audience may only catch a glimpse of what seems a static manifestation in development. The innate noise of living matter fosters a difference in expression from one experiment to the next, a variation that may lead to unpredictable behaviour. For galleries and museums, these parameters throw up challenges of replenishing material that can be experiments in their own rights especially during exhibitions lasting more than a couple of days. This suggests that an appropriate method to overcome such variables is to exhibit documentation. Whilst mediation of processes do not adequately address the implications of presenting the living, it highlights the difficulty facing curators and artists that often leads them to manufacture solutions that simulate life. For the purpose of this research, documentation served a dual role, (1) to provide experiments and outcomes with mobile documents (e.g. video or photos) to be exhibited independently or alongside the living, and (2) as an observational tool or method to steer the research through reflection, re-evaluation and refinement.

The research established an early need for documenting biological processes using photography and time-lapse. For instance, when working with growth experiments (Section 5.3) there were no in-house facilities to observe these changes as a continuous process over time. Similarly, challenges emerged during the development of *katE* (Section 5.6.1) in terms of recording growing colonies. A major obstacle in capturing stable photos at intervals without time-lapse facilities is that moving petri dishes to and from incubators can easily introduce spurts of growth around the plate (caused by movement of liquids). While *katE* suggested the inclusion of a *Growth barrel* using custom electronics, a simpler and modular solution was built (Illustration 58). Using medium-density fibreboards, the set-up was fitted with a hinged door and measured to enable A4 filters to be used as portable shelves.

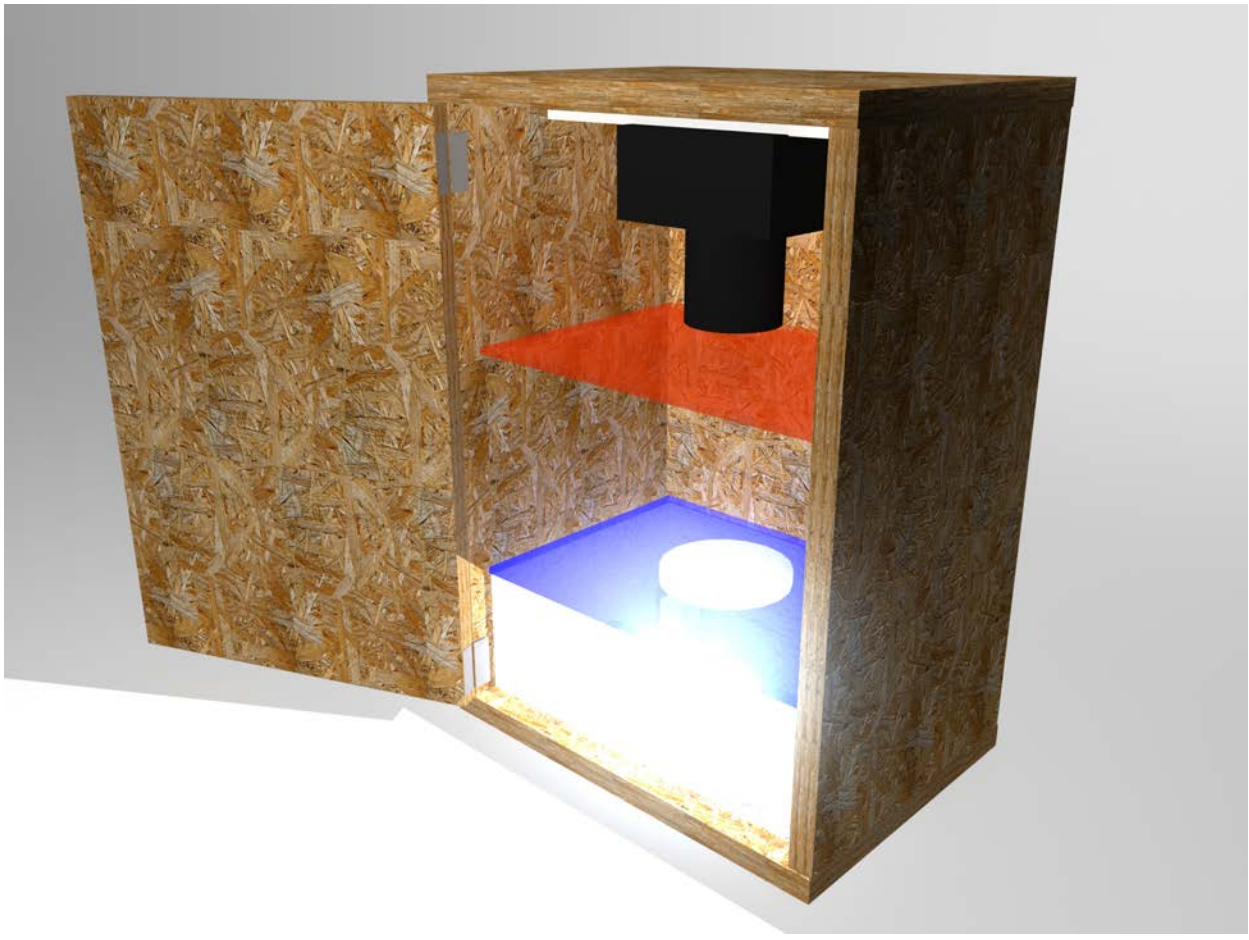

Illustration 58: 3D render of proposed set-up (Autodesk Maya, 2012). Illustration: Howard Boland.

To capture expressions of fluorescence, as in the work *katE*, a box equipped either with UV-light (that is damaging to cells) or a less invasive set-up such as a Darkreader (Section 4.16.4) was needed. Woodwork and light wiring was fairly straightforward but to introduce a non-invasive solution similar to the Darkreader (by implementing light source and filters) while keeping cost

low was difficult, since acquiring polarised filters was both expensive and complicated. A kind donation of a Darkreader from Clare Chemical Research (Section 6.4.1) helped overcome this challenge albeit later in the research. The Darkreader was not only interesting for documentation and evidence gathering but also for exhibition purposes and was used in *Stress-o-stat*.

The box was fitted with a metal bar in order to position a single-lens reflex camera (e.g. Canon SLR 300D and Canon SLR 400D) pointing down from the ceiling of the box (Illustration 59).

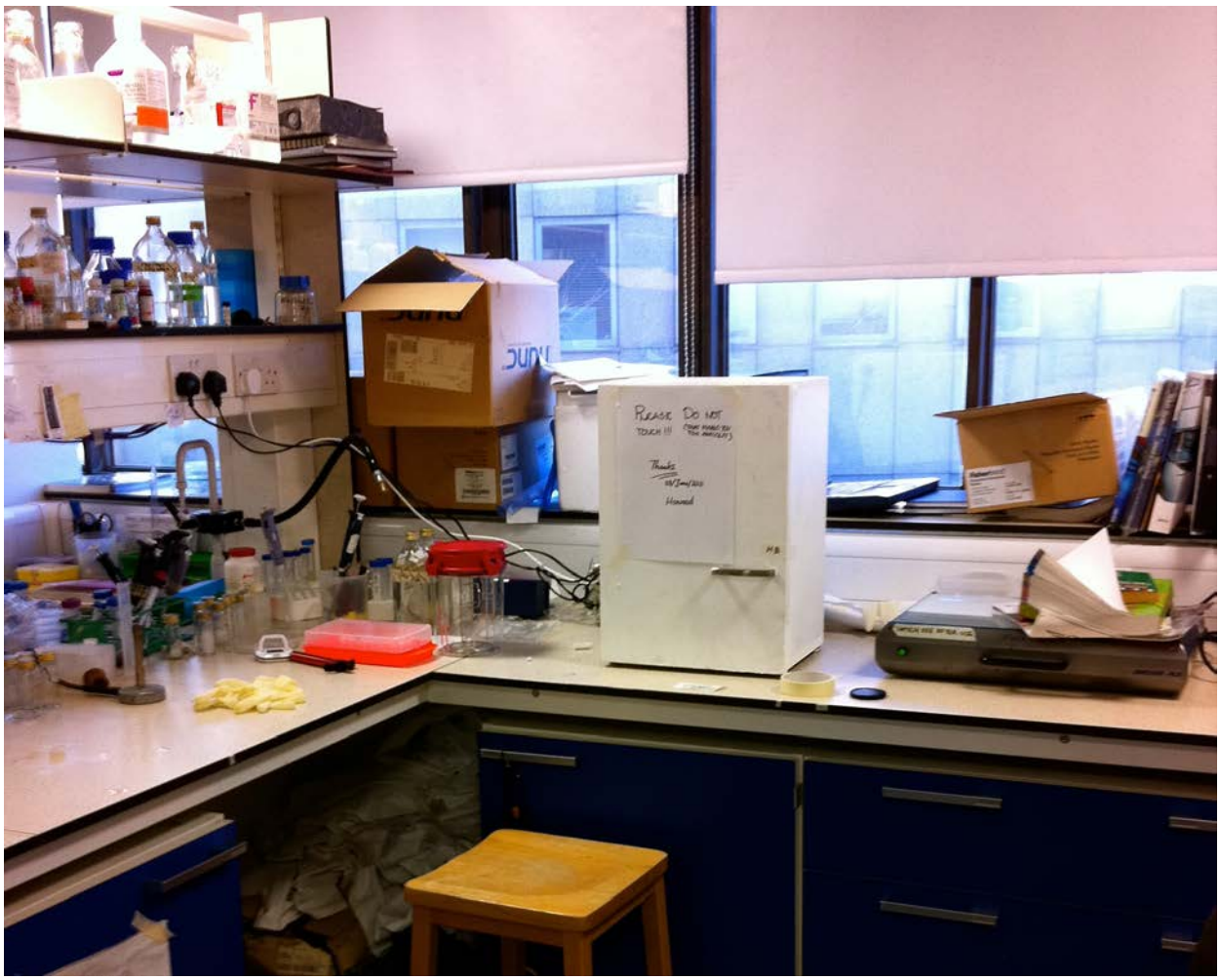

Illustration 59: Complete time-lapse facility set-up. Photo: Howard Boland.

Filters were used as shelves and the light source positioned at the base, the latter also provided sufficient heat for growth conditions (+30ºC). To capture images using time-lapse, the camera was connected to a computer installed with 'Canon Remote Capture' software and the image sequence was viewed as a continuous animation using Apple QuickTime. While the set-up could not be used to capture fluorescent proteins, it was instrumental in documenting time-lapse of colony development and in the project *Transient Images*, which involved the degradation of textile-dyes to produce images (see the following).

## 5.14 *Transient Images*

As a contingent researcher, in the sense of intently crossing disciplinary boundaries and making use of side-walks to discover new ideas (Till, 2009: 47), daily interactions through laboratory practice can open material opportunities. There are many advantages of engaging with specific institutional methods and materials and although this research is independent, working within these parameters more readily enables knowledge transfer. It was appropriate to explore ongoing institutional research to investigate if these harboured artistic potentials. Given the knowledge base established through practice there was already a background to guide this type of engagement.

The conceptualisation of *Transient Images* emerged from discussions with a colleague (Eustace Fernando) whose primary scientific research involves degrading textile dye into a non-toxic bi-product whilst generating electrical output. Its major concern deals with effluent textile dyes since these can be environmentally hazardous. Most coloured textile articles and leathers are treated with azo-dyes (also used in painters paint such as mineral oils) that subsequently can become toxic (i.e. aromatic amines)[110] in reduced environment of which a small number are carcinogenic (Brown and De Vito, 1993; Manu and Chaudhari, 2003; Lewinsky, 2007: 150-151). Environmental cleaning of effluent textile dye involves chemical processing, however, in recent years it has become possible to employ biological organisms to perform this task in a process known as bioremediation. In Fernando's research two types of bacteria cultures were used to degrade the dye, initially the marine organisms *Schewanella* and later a consortium of sewage bacteria (mostly *Clostridium* genus). Both cultures are capable of breaking down azo-dye by scavenging electrons and further transporting these onto a conducting graphite membrane (e.g. electrode) to generate small amounts of electricity. Of interest were how these cultures were converting the dye into a milky solution during anaerobic growth and further how adding oxygen at the end of this reaction could produce a blue-grey colour. As with *Living Mirror*, methods and material involved processes such as anaerobic culturing and developing special media compositions (Section 4.15). The main concept for *Transient Images* developed from working with growth and fermentation (Section 5.3, 5.6 & 5.7). The initial work considered degradation in terms of speed, inoculum and colour changes. Since several dyes exist, each degrading at a different speed, this could allow movement through gradients of colours. Multiple bottles containing culture with dye mixture were used together to form an image by varying the

[110] Potentially leading to methemoglobinemia a disorder known for reducing blood's ability to uptake oxygen similar to a genetic condition most famously described as the "blue men of Lurgan".

inoculum. The method attempted to produce an image using fast and slow degradation so that some cultures would reach complete degradation faster than others. An image would appear in a 'transient state' before disappearing into a milky transparent solution. Inversely (from the perspective of colour change), once this reaction completes, oxygen would be flushed in at various speeds to produce another 'in-between' image causing solutions to change from transparent to blue-grey. The latter reaction is a 100-fold faster than microbial degradation (e.g. 5 minutes as opposed to a range of 6 to 24 hours).

The experiment used high-performance liquid chromatography (HPLC) tubes (2 ml) reducing the amount of media needed for each experiment. Each tube was given a specific volume of inoculum (ranging from 0.1-1 ml) and filled with coloured (dye) media to make up a final volume (2 ml). Like a screen or a bitmap, bottles were organised in a matrix (e.g. 6x6 or 7x6) each acting as a 'pixel' for the image produced. Initial tests established volumes of inoculum required to generate contrasts. Given the time-span (e.g. 24 hours), the *Growth Chamber* (Section 5.13) was effective in capturing time-lapse of the experiment and became integral in generating visual outputs. Tubes were placed upside down on the diffusion filter with the camera pointing at the base of the tubes (Illustration 60).

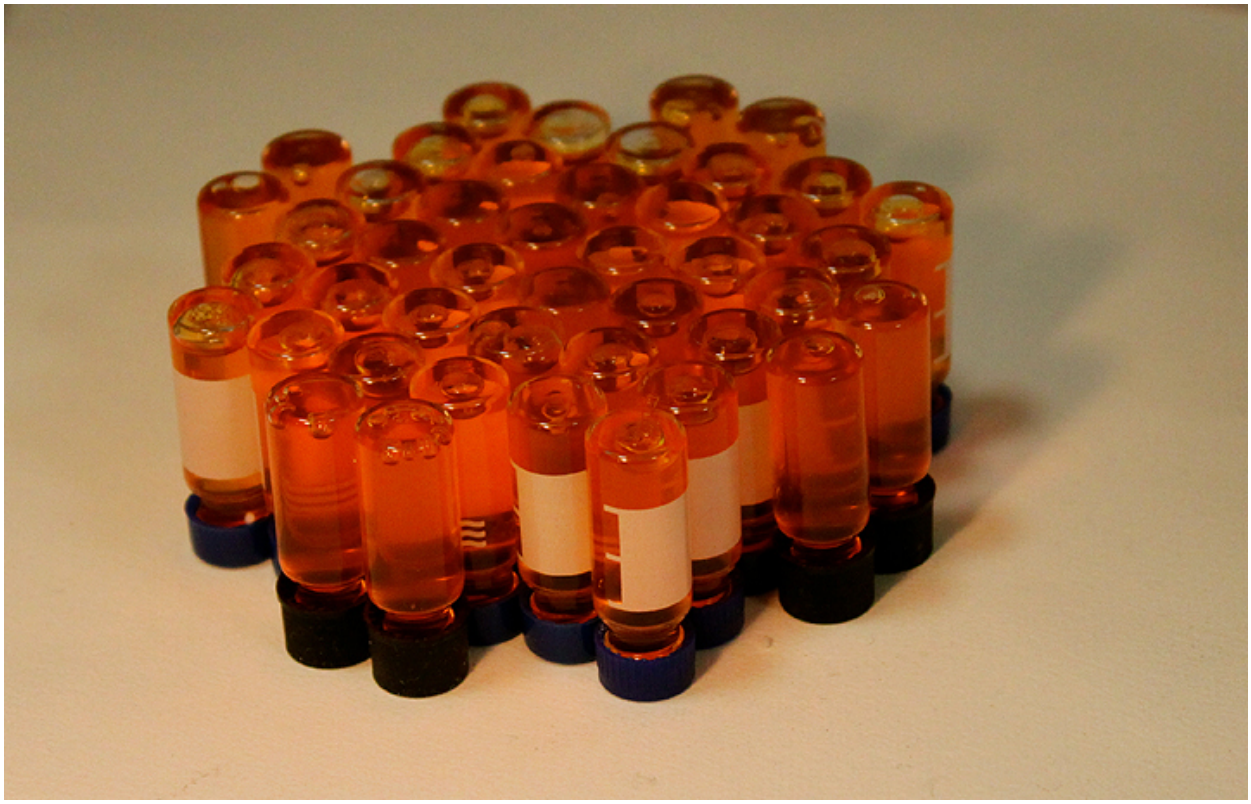

Illustration 60: HPLC tubes placed upside down (inside *Growth Chamber*). Photo: Howard Boland.

Notably, a previous work *Decon* (Menezes, 2007) also used bacteria capable of degrading (azo) dye. Set-up in a petri dish shaped like a rectangular canvas with several enclosure filled with agar media containing dye, it re-produced the deconstructive compositions of renowned Dutch artist Piet Mondrian's (1872-1944) *Composition in Red, Blue and Yellow* (Mondrian, 1930). *Decon* reflects on art historical notions of deconstruction that sought to redraw the figurative into abstraction, by a final disappearance of colour through dye degradation. While *Transient Images* clearly demarcates itself from this work, it partly shares material and methods. In *Decon*, degradation of azo-dyes was performed by *Pseudomonas putida* (Martins, 2009), a similarly pure culture to *Schewanella* used in early experiments but found aerobically sensitive. Instead, *Transient Images* use a consortium of sewage bacteria to enable more robustness to sterility, oxygen conditions and worked faster.

The use of sewage bacteria (donated by London sewage facilities) brings about negative experiences of grit and dirt such as smell of rot and is contrasted by their involvement in image production through their capabilities of bioremediation. As with previous studies and experiments, the approach was to establish a multi-perspective understanding of the organisms through use of microscopy to study swimming patterns and behaviour, to aspects involving smelling these cultures (Illustration 61).

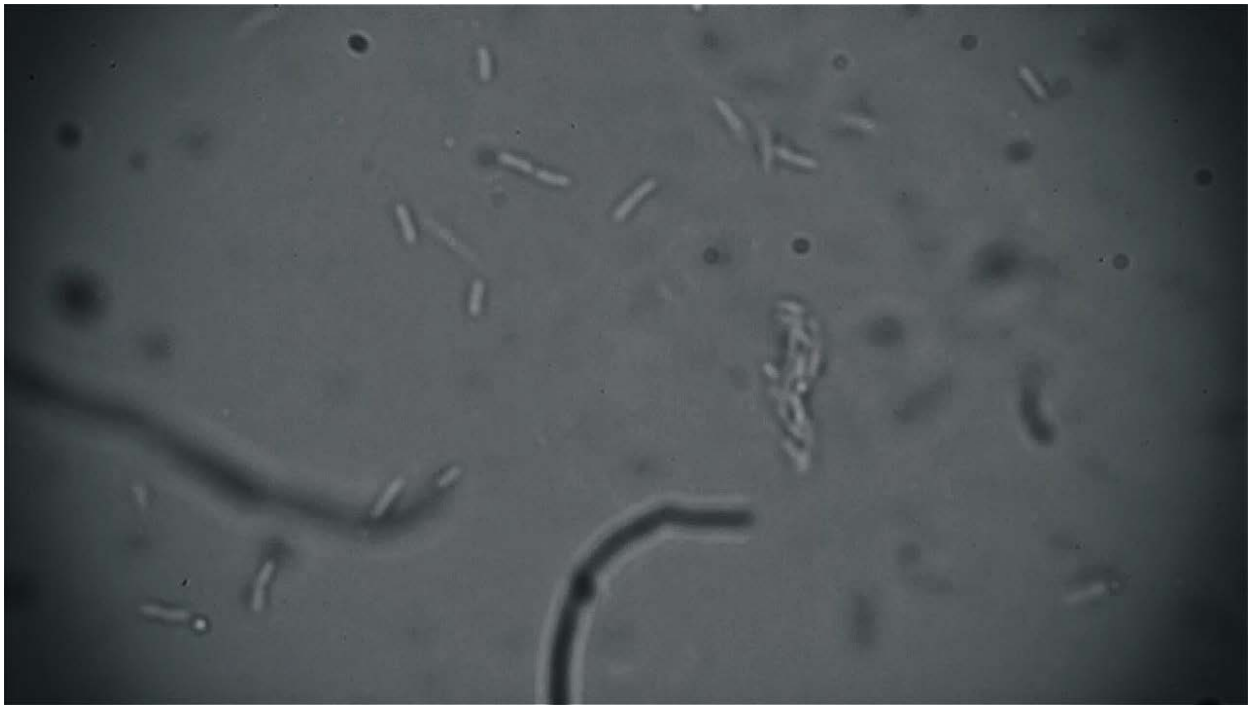

Illustration 61: Microscopy video still of sludge bacteria. Photo: Howard Boland.

Similar to low-resolution images, the visual information (i.e. number of pixels) available to convey an image or pattern was limited given the size of the grid (i.e. number of tubes). To overcome the challenge of producing recognisable visual elements, simple patterns were used and later images were also produced by using more tubes (e.g. 256 tubes) to increase resolution (Illustration 62).

Illustration 62: *Transient Images* degradation of dye. Photo: Howard Boland.

Initially, images took on organic forms by organising bottles with various inoculums in random fashion (e.g. simply by mixing these up). Methods were later established to produce defined symbols such as numbers and geometrical movements by gaining more control of degradation parameters (e.g. volumes, time, concentration). To expand on the potentials of the system as an image-making tool, a small web-based computer program (using HTML and Javascript / JQuery) was developed to simulate the degradation process and find a shared model between the virtual and the biological (i.e. a formula). An additional dimension for separation is the inclusion of continuous processes with logarithmic movement, in other words these images are subject to velocity and acceleration. By combining the living system and simulation program, image patterns could be explored and implemented providing a level of control and predictability. Like previous works, such as *katE* and *Stress-o-stat*, *Transient Images* attempted to establish visual outcomes through a level of control by manipulating living systems. The program suggested further potentials of building an automated system giving a direct connection between the images produced in the software and the biological system. This idea has links to *Stress-o-stat*

(Section 5.7) since it would require a controlled pumping and tubing system to be implemented in the array.

### 5.14.1 Towards a complete bio-system for bioremediation

While the consortium of bacteria may be able to produce a total degradation of the dye and its bi-products (e.g. aromatic amines), remaining components may be toxic and possibly carcinogenic. To complete the bioremediation, a bio system was proposed (Figure 25) by further modifying the media (e.g. by adding saw dust and dextrose [potato] broth) and inoculating it with fungi (i.e. *Pleurotis*) capable of converting this bi-product into a non-harmful substance.

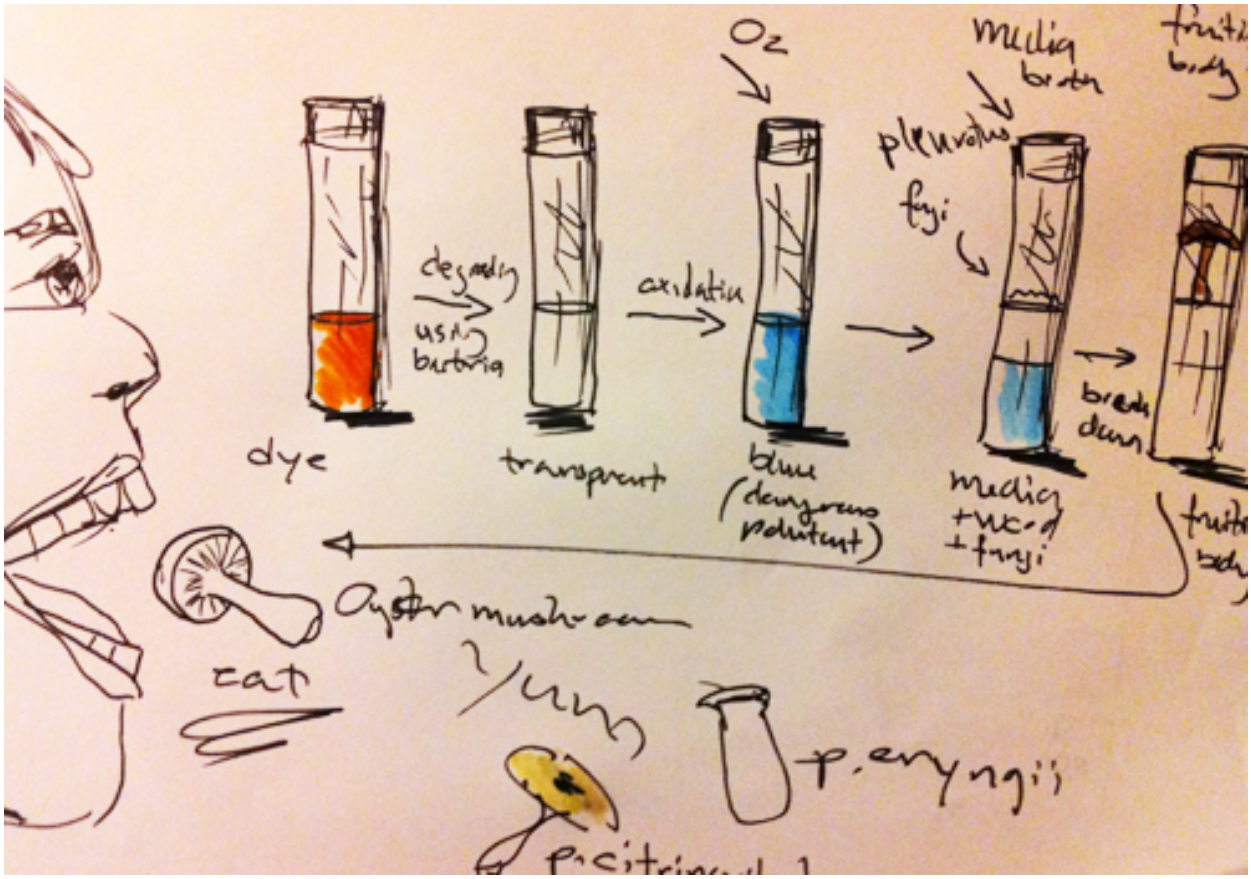


Figure 25: Sketch of suggested material flow involving bio-degradation followed by fungi takeover to remove all toxic substances and produce an edible mushroom. Illustration: Howard Boland.

The final step proposed growing these bottles in darkness to induce fruiting bodies or edible oyster mushrooms. As an extension to *Transient Images* it plays on the solidity of the scientific hypothesis, where resulting mushrooms are no longer toxic but edible, by challenging science peers to eat these. *Plurotis* were grown (Section 4.15.4) in attempt to produce these mushrooms using a semi-solid media consisting of potato agar and sawdust (Illustration 63). It was inoculated

with three disks of *Plerotis* fungi grown on agar, however, this did not yield mushrooms despite being grown in dark conditions at 30ºC for 3 months.

Illustration 63: Attempt to grow mushroom using a semi-solid media starting with plugs. Photo: Howard Boland.

It seemed unlikely; at least to my colleagues, that a take-over of a bacteria culture by fungi would be possible, and further, it would be challenging to generate a fruiting body as this processes take at least 1-2 months.

While beyond the scope of the research, developing a bio system offered potentials of extending the practice towards a biological machine configuration (i.e. automatic systems) that not only produces telling visuals but opens discussions to what role art can play in remediation.

*Transient Images* completes specific discussions surrounding the execution and outcome of this practice.

## 5.15 Summary

Discussions throughout this chapter show that scientific processes remain complex but artists can develop an independent practice given institutional access. For an immersive practice, methods became increasingly entrenched and informed by scientific practice, establishing a synergy between artistic and scientific processes through locating ways of experiencing molecular expressions in bacteria and developing these using scientific evidence-based laboratory practice.

The research identified methods (i.e. immersive laboratory practice, Chapter 4) appropriate for art practitioners to engage with biological knowledge (i.e. recombinant and synthetic biology) on a more profound level. As an immersive practice, the research moved from non-specific knowledge towards a level of competency in using scientific methods that paved the way for more ambitious works (such as *Living Mirror*). This was an appropriate methodology to undertake the practice and enabled innovative artistic outputs, such the work *katE* where novel genetic constructs were synthesised in order to visualise oxidative stress leading into the interactive setup *Stress-o-stat* that visualises this behaviour. Developing existing scientific material for the purpose of an artistic proposition, *Banana Bacteria* allowed genetically regulated olfactory expressions to be publicly experienced. In *Transient Images*, material was re-negotiated from a scientific context towards generating a process-based bioremediation-imaging tool.

These outcomes are distinguishable from many existing bio artworks that focus on aesthetics, ethics and cultural meanings often with anthropocentric tendencies. As discussed in Chapter 2, it has been argued that bio art is a distinct development within the history of art that produces subjects rather than objects, thus introducing and necessitating the negotiation of ethical dilemmas. Specific outcomes of the practice are informed by this background in the sense of being aimed at a public display of living artwork offering a level of immediacy rather than re-mediated through media such as videos or photography (Section 3.1.2).

The research provides a critique to how the field tackles the idea of subjectivity, cultural references and meaning processes. For instance, of those examples in bio art that involve genetic expressions, such as the use of fluorescence (e.g. Kac), these tend to give generic attention to why this is happening (i.e. colourisation of the organism or iconographic use of GMOs) rather than probing into the underlying mechanisms and behaviours governing these expressions (i.e. what the fluorescence signifies and its ability to function as a tool to visualise invisible processes). Genetics, as used here, is not merely an aesthetic tool but is understood as a network of interactions that can be tapped into to reveal (biochemical) messages and states. Pushing into

this area of genetics positions the works in a complex realm that make them challenging to communicate (instantaneously) but this is also where we might be able to get intimate with the organism and its genetic makeup. The artworks therefore seek to move away from an increasing and worrying obsession with using biological organisms to reflect on human conditions that promote a continuous exploitation and domination inadequate to address a second condition in bio art – the production of subjects. With works mostly employing bacteria, understanding subjectivity does not apply in a normal sense (e.g. individual or specific living) rather it is here discussed as a type of insight we may gain by using molecular tools. The focus is subtle, driven by observation and exploration away from human condition and directed towards the organisms. Starting with a practical critical inquiry that explores counter positions (e.g. painting with bacteria) it sought to locate accepted parameters of working. This suggests that there are deeper connections to be established with the organisms by following a molecular storyline rather than appropriating cultural meanings onto the living.

Potentials in synthetic biology have attracted practitioners from adjoining fields (e.g. architecture and design) however few work directly with the media but develop speculative ideas mediated through videos, illustrations, photography or conceptual objects (Section 2.4 & 3.1). This research argues the need for actual material engagement that can generate concrete outcomes rather than purely speculative approaches to biotechnology, which is often celebrated as futuristic and visionary (e.g. Ginsberg and Armstrong). For instance, the iGEM project *E.chromi* by Cambridge iGEM 2009, where a multi-colour pigment reporting system was developed, generated much publicity as a result of designers Ginsberg and James King's visual identity and speculative idea of using the system in gut bacteria to indicate potential diseases in human faeces. The exhibited outcome (e.g. MoMA NYC) showed several speckled coloured plastic stools in a branded suitcase and is clearly detached from material approaches employed by this research. Certainly, speculative design has gained momentum in recent years (e.g. RCA) with an increased focus on synthetic biology but remains on the side of conceptual practices. Going beyond the speculative and doing the work (as described in this chapter) offers a less fanciful vision by choosing not to ignore limitations but establishes ground rules of what can be accomplished. In tackling bio media, this research unfolds an awareness to risk of 'failure' involved in genetic engineering that may help explain why practices stop at an instrumental level (e.g. building a display to show something or instrumental intervention) and highlight the need to be ardent in breaking down these barriers in order to reach into the molecular. In this sense, the research aligns itself with practitioners who work to exhibit actual living material.

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# Chapter 6
# Public dissemination and exhibitions

## 6.1 Introduction

This chapter deals with dissemination of practice and staging artworks in the public domain. The practice provided a framework for conceptualising and producing bio artworks using molecular and synthetic biology, however, an additional set of challenges faces practitioners attempting to exhibit GMOs. In itself, this activity contributes to the research findings by identifying an existing gap in exhibiting artworks involving GMOs within the UK. This chapter looks at what can be learnt from exhibiting living synthetic biology artworks and how regulatory frameworks must be negotiated.

Discussed first are curatorial and advisory engagements with various organisations, particularly through my involvement as an iGEM advisor. As mentioned, iGEM is an annual student-led competition that substantially influences, contributes and expands the Registry of Standardised Parts through submissions of new BioBricks™. This also involved critical engagement in synthetic biology through public activities and addressing issues of ownership and access to these technologies as discussed in section 2.2.

### 6.1.1 UCL iGEM 2011, *Ecoili*

Discussions with Darren Nesbeth (UCL Bioengineering Department) on A3 assembly processes (Section 4.14.2) and iGEM opened an invitation to join the UCL iGEM 2011 team. The project involved DNA supercoiling, a topological state, generated by enzymes (i.e. *topoisomerase*, specifically *gyrase*) to either relax or overwind DNA during specific events such as cell division and transcription (Illustration 64). The aim was to generate a plasmid DNA delivery system for use in gene therapy.

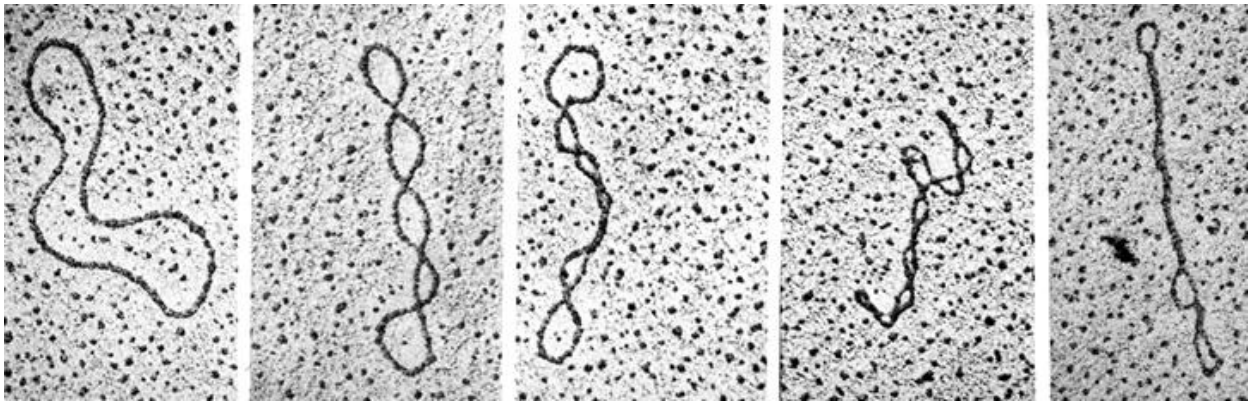

Illustration 64: Electron micrograph of DNA (mini ColE1 plasmid dimer, 5 kb), selected to show degrees of supercoiling from fully relaxed (left) to tightly coiled (right). (Courtesy of Ms L Polder). From Kornberg, A., *DNA Replication*, 2nd edition, p.36, W. H. Freeman (Kornberg and Baker, 2006). Permission to reuse granted by University Science Books.

The project involved multiple outcomes ranging from wet laboratory work, documentation using a website (wiki) and human practices, and provided significant insight into how these teams operate and the material quality that underpins the library. As an iGEM advisor, I instigated an event and exhibition "Synthetic Biology: Machine or Life?" (Antoniw, 2011; Cinti, 2011d). Held at the Science Museum's Dana Centre it was aimed at displaying living synthetic biology artworks and identified a gap in knowledge on the subject of exhibiting GMO (discussed in section 6.2).

### 6.1.2 Yes Biotechnology, *Nutristick*

Concurrently with participation in the iGEM 2011 competition, I also participated with a team of PhD students from the School of Life sciences (University of Westminster) in the entrepreneurial competition 'Yes Biotechnology' organised by the Biotechnology and Biological Science Research Council (BBSRC). It involved pitching a potential commercial biotech-product and business-plan to investors. Our product, the *Nutristick*, was a self-powered measuring device that could be plunged into soil or water to provide farmers with information about conditions in the field through a remote sensing system powered by soil bacteria (Figure 26). Notably, the device used similar electron transfer mechanisms to *Transient Images* (Section 5.14) that can degrade dye and produce electrical output.

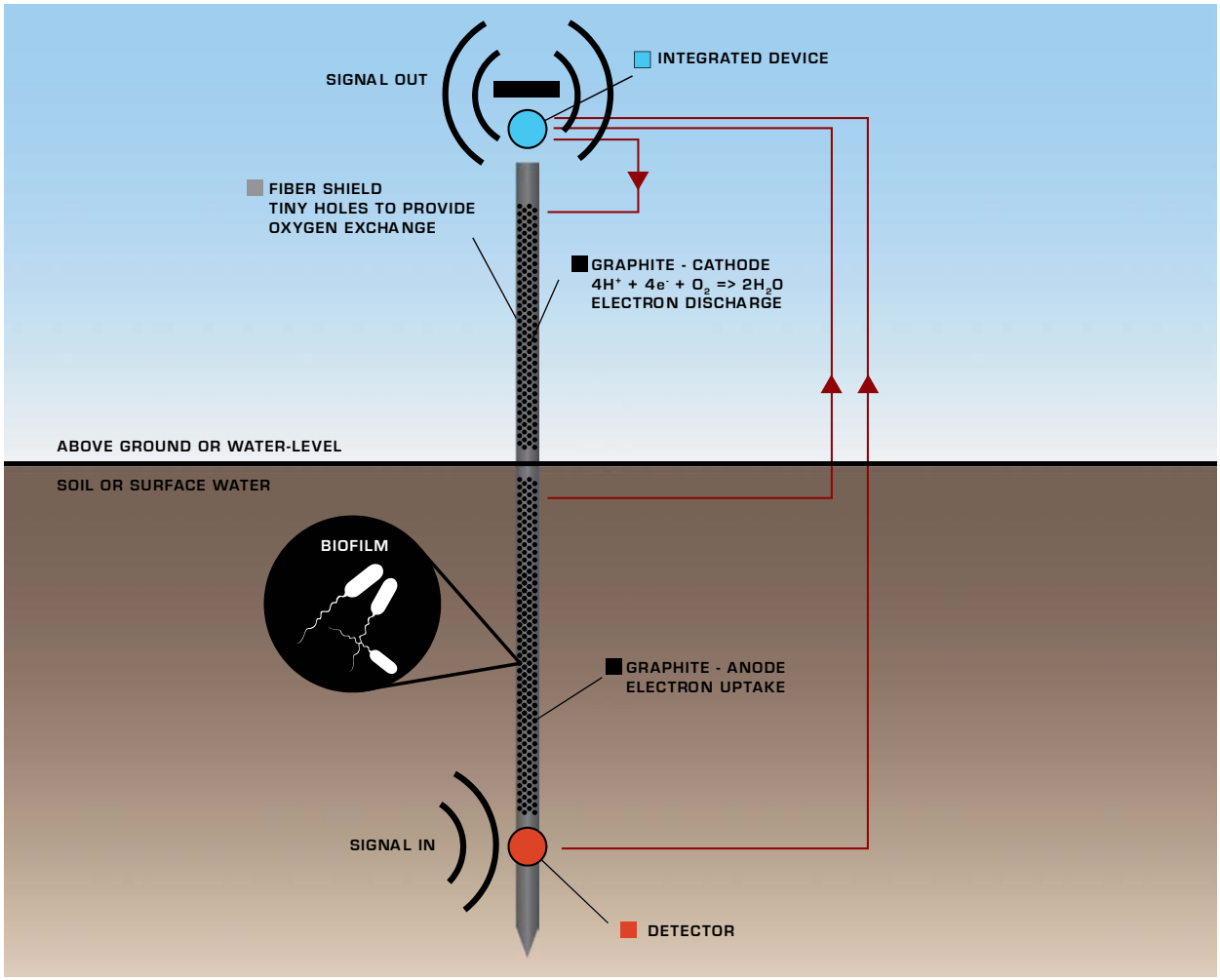


Figure 26: Outline of the device *Nutristick* produced as part of the University of Westminster's 'Yes Biotechnology' team. The device proposed using microbes found in soil or water to provide sustainable energy solution for remote monitoring of crop conditions (e.g. pH of soil). Illustration: Howard Boland.

The competition helped establish a good working relationship with scientific colleagues and gave insight into how ideas are generated within this community (amongst peers in the competition). Further, it provided insight into how scientific research may become converted into products, an aspect often forgotten in daily laboratory work, and how elements such as trials and costs influence research outlooks.

### 6.1.3 UCL iGEM 2012, *Plastic Republic*

After completing the 2011 iGEM competition a meeting consolidated lessons towards establishing the 2012 UCL team. Of importance was how the idea was generated, deadlines, consistency and funding. For instance, in previous competitions, the idea was handed to the team by academics rather than being generated by students and given that a new group started afresh each year, there was no learning to be transmitted from previous years. The 2012 team managed to obtain funding from the Wellcome Trust, Crowd funding (using Sponsume)

amongst others. The previous year's student coordinator (Philipp Böeing) retained the role and I continued as an advisor. I generated and pushed forward the project idea *Plastic Republic* that involved building several synthetic biology devices that could be implemented in sea-born microorganisms to bind plastic in the Pacific Gyre with the ultimate vision of clumping large amounts of material to generate islands. Given the radical proposition of introducing GMOs into the oceans, we organised a public discussion inviting a broader range of stakeholders (including Bloomberg, the Guardian, London Futurists and London Hackspace) to discuss such prospects (Boeing, 2012; Cinti, 2012d). We worked with a DIY biology group from London Hackspace and taught its members techniques in synthetic biology in order to generate the first public BioBricks™ (i.e. anti-freeze and mercury degrading genes) and celebrated this accomplishment with a performative exhibition and discussion at the Grant Museum of Zoology (Cinti, 2012c). As part of this exhibition, I also built a display to visualise the BioBricks™ in real-time (Illustration 65).

The latter engagement with DIY biologists and electronics hackers was useful despite coming at the end of the research. For instance, a continuous challenge facing artists working in laboratory spaces is the need to access other types of workshops (such as the space of London Hackspace) to build tools, installations and hosting displays (such as the custom made plinth to visualise DNA seen in Illustration 65). Certainly, having access to mechanical and electronic workspaces alongside a biological laboratory is highly beneficial for artists (and scientists).

Illustration 65: *Right or Risk?* (2012). Real-time visualisation of the first BioBricks™ generated in the public domain. Display consists of blue acrylic plastic, transilluminator, Darkreader and open gel box. Photo: Laura Cinti

### 6.1.4 Westminster iGEM 2012, *iSTEM*

Given my experience with UCL iGEM 2011, I proposed that University of Westminster initiated an iGEM team. A proposal was forwarded and approved by academics at the School of Life Sciences. The school agreed to cover the cost of establishing a team and its participation in the regional final (i.e. European Jamboree). Given that it was a new activity in the school, it took time for both students and staff to gain the experience needed to initiate project ideas and establish a consistent team. Two ideas were explored: the first relating to enzymatic degradation of chewing gum, which was assayed but did not work, and the second to build several BioBricks™ for use in human genetics to identify, isolate and destroy cancer stem-cells. Establishing the groundwork left little time to do laboratory work and working with mammalian cells added complications to the system since relatively few parts could be found in the library and had to be sourced outside (e.g. a mammalian BioBricks™ library, Centre for Genomic Regulation, and several mammalian parts from Denmark Technical University). The work provided an opportunity to explore multi-part assembly methods such as 'Plug n' play' (or USER-cloning) and offered useful insights in working with non-bacterial genetic systems, such as those of humans, which are significantly more complex than bacterial systems in terms of signalling, transcription and translation.

### 6.2 Synthetic biology exhibition Dana Centre: Synthetic Biology - Life or Machine?

The event "Synthetic Biology – Life or Machine" at the Dana Centre held on the 20th October 2011 involved an exhibition and a panel discussion. The exhibition proposed showing living GMO artworks developed through my research and also video screenings thematically related to synthetic biology by artists and designers (Cinti, 2011d).

The overall aim of the event was to provide a reflection on the machine-like language and metaphors used in synthetic biology to discuss life and bio matter. Since it represents a meeting point between biology and engineering practice there has been transference of many concepts onto the biological such as circuits, devices and chassis (Section 5.7). In many ways these mappings suggest a desire to see life as machines. While notions of machine and life have a ramified place in the history of ideas (e.g. Heraclitus of Ephesus, Julien Offray de La Mettrie, etc.), these stories re-emerge in synthetic biology in the sense that life is understood as a machine-like 'device'. These notions are also explored in *Stress-o-stat* where a genetic stress-sensing device (a plasmid generated using synthetic biology) interfaces with life processes (visualising oxidative stress) controlled by a chemostat (machine). Appropriately we provided the organisers with a photo of *Stress-o-stat*, which was used in the poster for the event (Illustration 66).

While the aim had been to exhibit two living installations involving GMOs, *Stress-o-stat* and *Banana Bacteria*, these had to be retracted only days prior to the event due to formal concerns raised by the University of Westminster after consulting the Health and Safety Executive (HSE)[111]. A suggestion of simulating *Stress-o-stat* using a natural bioluminescent organism (i.e. *Vibrio Fischeri*) was rejected, as this would have been inconsistent with the aims of the research described here (Chapter 3). Cancelling what would have been the first art exhibition of this kind in the UK was a setback, however, the event went ahead with screenings and debates attracting a full house of 80 attendees. The discussions highlighted a need for more background information on synthetic biology in order to explore notions of machine and life more extensively.

[111] UK governmental body governing health and safety issues.

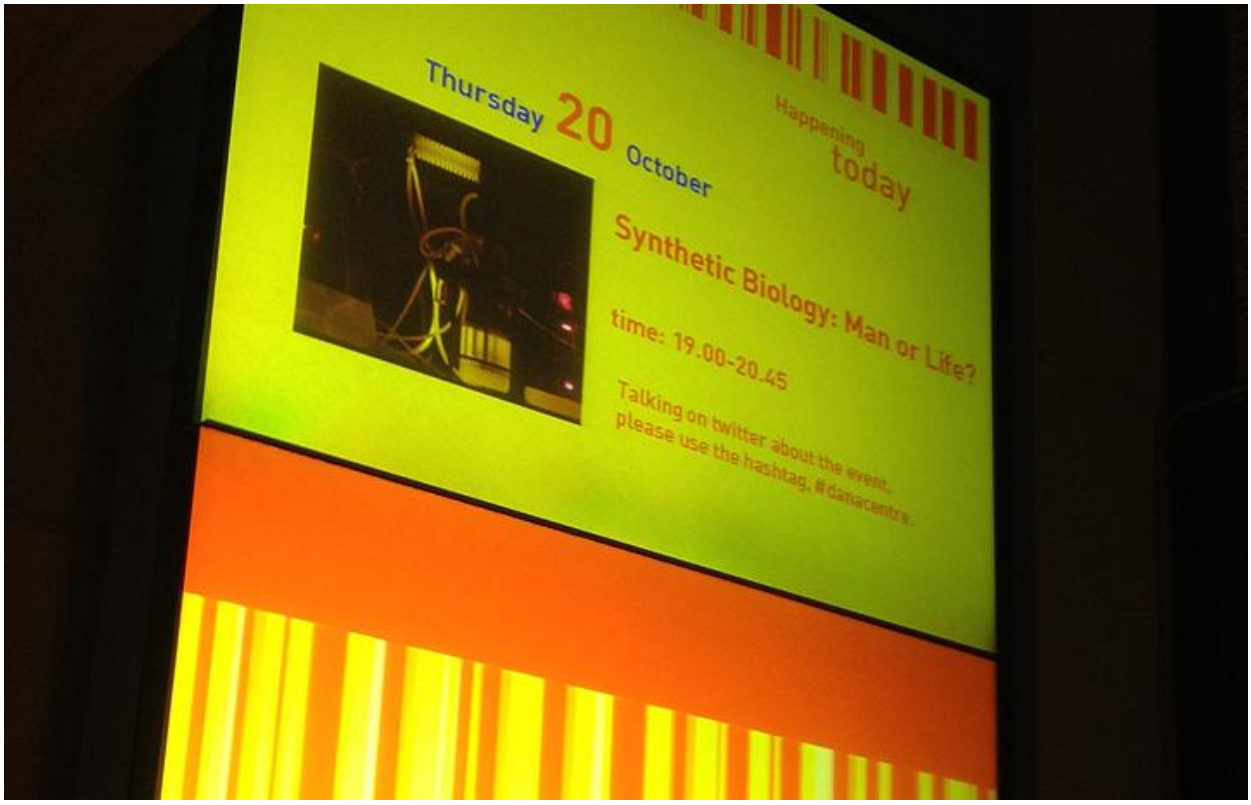


Illustration 66: Poster showing *Stress-o-stat* as part of the DANA Centre's 'Synthetic Biology: Machine or Life?' event. Photo: Howard Boland.

The thoughts expressed by the audience suggested disenchantment with the possibility of having any impact on either the field or the policies governing it. As mentioned, it was particularly this question of ownership that helped re-direct the 2012 UCL iGEM public outreach programme towards synthetic biology in the public domain (Section 6.1.3).

## 6.3 Exhibiting GMOs in the UK

Whilst knowledge processes governing the production of such works involves a great deal of learning for artists, subsequent challenges follow when attempting to publicly stage these works. For instance in the UK, tissue culture has been exhibited on several occasions (e.g. the Wellcome Trust, GV Art Gallery, FACT Arts Centre), but exhibiting GMO is a relatively new activity and it was difficult to locate any previous example of such displays - a gap addressed in the research.

Seemingly in the past, several art exhibitions have featured GMO in the UK. For instance: Critical Art Ensemble's *GenTerra* (Critical Art Ensemble and Costa, 2001) supposedly exposed GMO bacteria to the environment at the Darwin Centre, Natural History Museum, London; In Jun Takita's *Light, only Light* (Takita, 2004) transgenic moss was intended to be exhibited at *Sk-interfaces*, FACT Arts Centre, Liverpool, but was replaced with unmodified moss; and though not

in the UK, Eduardo Kac's *Eduina* (Kac, 2009a), a genetically modified plant containing a gene from the artist was exhibited at the Science Museum Dublin, however, a PCR verification showed no traces of human genetic material (Gorman, 2011). Claims of exhibiting such material as art at least in the UK remain uncertain and it is difficult for the public to verify such assertions.

Notably, there are conflicting understandings in how regulations are governed when exhibiting bio matter such human tissue (i.e. Human Tissue Act) and GMO. Many exhibitions have been set-up using natural organisms (e.g. plants, fungi, bacteria) and, in most cases (apart from pathogens, viruses, etc), these do not require artists to negotiate regulations.

A major institutional concern is media attention generated by an exhibition leading to negative publicity. While the UK has seen a departure from the negative debates surrounding GMO around 2000s to the more positive outlook toward synthetic biology of today (2012), it remains unclear how well these opinions are informed and the extent these are maintained over time.

To establish a framework to overcome such challenges, discussions with the HSE showed that it is possible to exhibit GMO by extending existing institutional GMO licensing to include external premises. In addition, an application was made to the University ethics committee and endorsed (Appendix XXIII). These processes show that an agreement can be reached on exhibiting GMOs in the UK. However, it is unlikely that curators are aware of the efforts involved in producing and organising exhibitions with GMOs. Thus, this research recognises a need to see a clearer regulatory framework developed allowing artists to exhibit art or perform activities involving GMOs.

The processes of obtaining ethics approval included providing a complete set of forms for the Control of Substances Hazardous to Health (COSHH) that explicitly states risks in handling substances used in each experiment and forms describing the research aims, methods and reason for needing ethical approval. It was also a requirement to be familiarised with the 'Brenner Scheme' (HSE, 1997) to understand and assess risks associated with GMOs. The process can be administratively lengthily (i.e. subject to set committee meeting and institutional procedures), for instance it took 7 months for the application to be formally accepted. The assessment showed that the works developed through this research poses minimal risks to human health and the environment (Appendix XXIII). Following this, as mentioned, the process of exhibiting GMOs involves either extending the University GMO licence (at no additional costs) by notifying HSE,

or obtaining a separate licence for the venue at a cost of around £500 per venue which includes a required a safety inspection.

While regulations vary from country to country and several exhibitions involving GMOs have taken place (e.g. United States), they are often set on institutional premises. The additional factor often ignored is the need to re-produce bio artworks for exhibitions and therefore preparation of material can be time consuming. Given the outcome of the Dana Centre exhibition, I decided to push forward more persuasively with an upcoming exhibition in Mumbai (India) and actually exhibit living synthetic biology works.

## 6.4 First Living (GMO) Synthetic Biology Exhibition: Techfest, India

Given UK specific background, *Stress-o-stat* and *Banana Bacteria* premiered in Mumbai, India (6-9th January 2012, IIT Bombay, 2012) and was the first public exhibition involving living molecular synthetic biology artworks. Examples of thematically related exhibitions include 'Synth-ethics' in Vienna (Hauser and Schmidt, 2011) which either (1) re-introduces several earlier bio artworks as synthetic biology by attempting to thematically relate or (2) shows visuals such as videos or designs that directly relate to synthetic biology (see section 2.5.4 for a discussion on other bio art exhibitions). Like the proposed UK exhibition (at the Science Museum's Dana Centre), *Banana Bacteria* and *Stress-o-stat* were selected as the most appropriate to exhibit since they complemented each other by means of sensorial interaction. For instance, *Banana Bacteria* provided an olfactory experience that could also be contrasted with the 'natural' smell of *Stress-o-stat* and vice versa for the visual experience through fluorescent stress-regulation. Exhibiting these artworks was possible as the event was hosted within a research institute with the required GMO licence to both grow and prepare this material.

### 6.4.1 Techfest: Preparation

As outlined and reiterated there is plenty of scope for technical problems facing bio art practitioners (Section 2.5.2). Not completely unlike digital technology, the material often fails to 'perform' as intended during exhibition due to 'bio-technical' glitches. Unlike other exhibits (e.g. digital and robotics that may need re-assembly) at the Techfest exhibition, the need to grow these exhibits on site is a relatively new requirement and often an experiment in itself. The many dependencies open these works to risks that curators need to be aware of, if not appreciate. Living exhibitions are constrained by life expectancy that does not necessarily adhere to an exhibition programme - a particular challenge for long-term exhibitions (e.g. 1-6 months). How

funders and artists justify short exhibitions given efforts of setting up complex displays point to reasons why many curators and artists choose to show documentation, rudimentary artefacts or 'fakes' (i.e. dead and preserved but seemingly living specimens) as opposed to the living. This may also provide a justification to why festivals are a more common place to find such works (Section 2.5.4). Since *Banana Bacteria* and *Stress-o-stat* both employed *E. coli,* a short exhibition period was appropriate and even so there was a need to replenish material. The latter should not be confused with public maintenance of biological matter such as watering plants but require more specific understandings of the material used.

With potential complication of setting up in a foreign laboratory, a technical rider was sent specifying necessary arrangements needed to prepare material in a laboratory space and with protocols adhering to UK safety standards. Prior to the exhibition, protocols were revised and media components weighed out to ease preparation upon arrival. The material was shipped from one research institute to another[112] and special care was taken to prepare living matter (e.g. stab cultures and miniature plates) and sensitive material. Correspondence with Clare Chemical Research (Mark Seville) resulted in a kind donation of a Darkreader that included five orange filtered glasses[113] used in *Stress-o-stat*.

### 6.4.2 Techfest: Setting up

Setting up the works, involved growing material from small to large volumes and reconstructing the installation. The wet work was performed by myself and access to a laboratory space was provided by Biological Systems Engineering Laboratory (BSEL) at the Indian Institute of Technology (IIT), Bombay (Cinti, 2012b).

Preparation on site was helped by Cinti (of C-LAB) co-exhibiting the work 'Nanomagnetic Plants' (Cinti, 2011a) where plants embedded with magnetic nanoparticles become movable using an external magnet (see also section 5.12). Techfest primarily focuses on robotics and digital technology and organisers had limited background dealing with international exhibitors requiring laboratory access. Pramod Wangikar of BSEL was most accommodating by lending their fermentation unit (a highly-prized resource for the department) and liaised the work by providing time with his researchers Krishna Kumar and Sandeep B. Gaudana.

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[112] A standard and legal procedure of exchanging this type of material between institutions.

[113] While my University owned similar equipment, it would need decontamination due to use in agarose gels analysis that contain Ethidium Bromide.

Preparing these artworks in unfamiliar laboratory facilities can be disorienting and conditions and code of conduct often vary (Illustration 67). For instance, while IIT Bombay is a premier centre for research and higher education (Shrikanth, 2011), researchers are required to be resourceful to overcome sometimes limited funding and material. The preparation of the work involved a three-step process: (1) preparation of media and its components, (2) growing organisms and (3) preparation of displays. For *Banana Bacteria* minimal media (M9) was prepared (Section 4.15.2 & 5.8) and LB-broth for *Stress-o-stat*.

Illustration 67: Preparing material for exhibition at BSEL. Photo: Laura Cinti.

Requirements for *Banana bacteria* were two round bottom flasks fixed on a laboratory stand on two levels (Illustration 68). *Stress-o-stat* was a more challenging set-up involving additional material for functionality such as pumps, tubes and glassware.

Despite challenges of working in different laboratory settings, the preparation for *Stress-o-stat* went as planned: I am indebted to researchers at the institute who generously provided resources. Some of the material had to be sourced from the laboratory and the final display is partly influenced by this. Like previous set-ups, it included a fermentation unit, pumps, a

condenser and a Darkreader. The system was transported from the laboratory to the exhibition and securely mounted.

Illustration 68: Exhibition of *Banana Bacteria* - audience smelling the work. Photo: Howard Boland.

### 6.4.3 Techfest: Exhibition and reflection

Visualising fluorescence worked well by giving audiences orange filtered glasses and bright light conditions were compensated using a UV-light (Illustration 69). A dark space would have been more visually effective but increased the risks of bumping the displays. To avoid overcrowding it was advised to use posters (A1 format) accompanying each display to provide information and limiting the interactive experience. The exhibition had more than 90,000 visitors over four days and can be understood as a multi-dimensional festival (i.e. Asia's largest festival focusing on science and technology) rather than a specific art exhibition. Speaking with the audience, both *Stress-o-stat* and *Banana Bacteria* were well received but the exhibition highlighted a set of challenges facing organisers wanting to include living synthetic biology art.

Illustration 69: Exhibition of *Stress-o-stat*, audience looking at display using polarised glasses. Photo: Howard Boland.

As the first exhibition involving these types of material transactions it was noted that the overall focus on technology may impact the living by simply rendering as part of this category and it would be useful to provide a space that accommodates more intimacy. That being said - surrounded by robotics and artificial intelligence technology is also an appropriate context that highlights the meeting point between life, machine and social interaction.

## 6.5 Cage Rattling #1: Kill Switch

Following the Techfest exhibition, this research returned to its focus on establishing a UK exhibition involving GMOs. A radio interview on this research[114] led to an invitation to exhibit *Stress-o-stat* as part the event titled 'Cage Rattling #1: The Kill Switch'[115] with reference to synthetic biology through the Cage's use of algorithms and engagement with nature (Sherrard, 2012). It aimed at incorporating both actual living synthetic biology art as in *Stress-o-stat* and performative uses such as musicians only playing the notes A, D, C and G with reference to the genetic bases (A, T, C and G). The venue, Kings Place (London), was registered with HSE

[114] Hosted by Resonance FM's Regine Debatty (Cinti, 2012a; Debatty, 2012).

[115] The event was part of a series celebrating the composer John Cage's centennial (briefly mentioned in 3.1.2).

providing it with an extended permit to show GMOs. A meeting was also held with the venue host to explain the nature of the exhibit (i.e. hosting genetically modified bacteria that would produce light in response to stress) and the necessary requirements.

Two days were spent preparing the safety aspect of exhibit and four days reproducing the material for the work. A major obstacle was arranging and transporting the work from the laboratory (Illustration 70)[116].

Illustration 70: Transportation of *Stress-o-stat* for the exhibition. Photo: Laura Cinti.

As required, the vessel containing the GMO culture was placed in a yellow biohazard bag, causing alert amongst safety officers at the venue and after much commotion, the venue decided to effectively shut down my exhibit leaving it mounted without the presence of the bacteria. In spite of having agreed to this prior to the event, it highlighted unjustified health and safety issues due to the packaging (i.e. biohazard bags). While this exhibition had all the necessary paperwork in place, it showed that a more comprehensive conversation with all parties involves (i.e. venue management and organisers) is needed in order to understand the processes of exhibiting such material (i.e. transportation material).

[116] For instance, it involved preparation of forms for removal of equipment from the laboratory, packing and labelling of material with biohazard stickers. In addition, the culture was kept in a biohazard bags and a mini-van used for transport labelled with appropriate biohazard stickers.

## 6.6 Re-New Digital Arts Festival

*Stress-o-stat* was also invited to be shown at the annual 'Re-New Digital Arts Festival at Aalborg University' (Boland, 2012b; re-new.org, 2012). A detailed technical rider had been provided six months in advance and the organisers had made attempts to arrange a GMO permit to show the work within the institution. However, two weeks prior to the event I was notified that the exhibit would not be possible and "it appears to be illegal (in fact) to do this in [Denmark] 'live"' (Søndergaard, 2012)[117]. It was decided to try an alternative display using fluorescent dye to illustrate the concept. While it was useful to try out the simulated version (Illustration 71), I concluded that such presence was near meaningless in terms of what the artwork was trying to do, and this also concurred with my intuition for not pursuing this for the Dana Centre event (Section 6.2). An interesting aspect for this event was the extent digital and sonic artworks attempted to draw references to the production of 'life-like' behaviour. In relation to discussion in section 3.1, the exhibition accentuated the disparities between digital simulation of life versus actual living materiality in bio art.

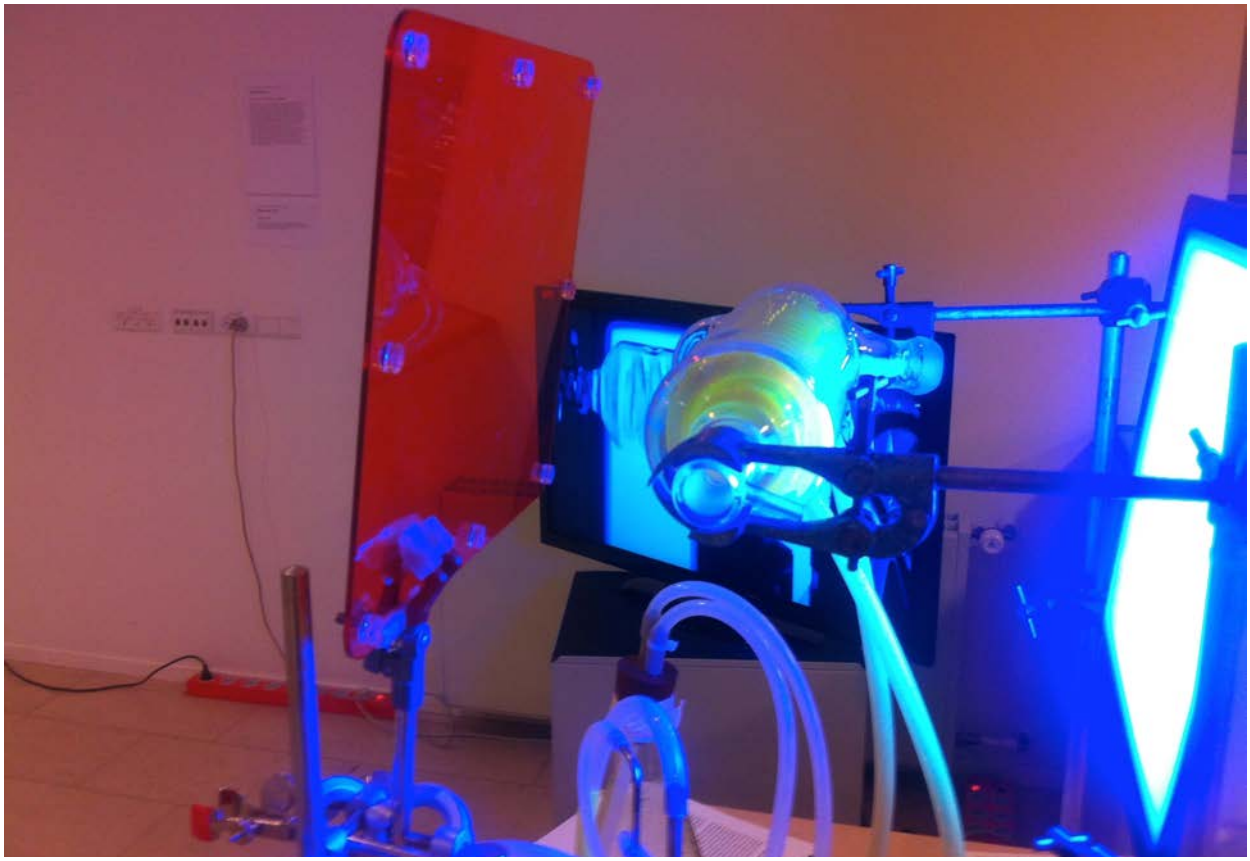

Illustration 71: *Stress-o-stat* with fluorescent dye (photograph taken with mobile phone [Apple iPhone 4]). Photo: Howard Boland.

[117] Upon arrival it became clear that it was not a question of legality but that the newly established bioscience department was actually having a permit inspection concurrently with the exhibition and was worried of having a separate case running for the exhibit.

## 6.7 Stakeholder perspective on exhibiting GMOs in the UK

In concluding this research and towards its final exhibition, several stakeholders in the UK were contacted. Based on the accumulated experience of dealing with exhibiting GMOs what had become clear was that this research could not only offer a framework, but also generate this first exhibition of its kind in the UK. These conversations highlighted that even amongst key stakeholders in art and science there is a tendency to conflate exhibiting human tissue with GMOs. As one curator put it:

> […] However, to exhibit your artwork the gallery would need a licence for the display of living tissues. I would therefore recommend that you contact the art gallery GVArt which is one of the few places in London which has been granted such licence. (Albano, 2011)

While the statement suggests that exhibiting GMOs required a licence for displaying living tissue and this has already been granted by one London venue, the licence referred to is actually the aforementioned HTA licence that is regulated completely differently to GMOs and can be obtained online for a fee (Section 6.3). As a statement this is far from unique, but one of several that suggests a broader need for stakeholders to become informed of these regulatory processes. As it stands artists rather than curators and organisers are the ones actively negotiating these processes.

## 6.8 Summary

The research benefited from its curatorial and advisory involvements as it informed both thematic and stakeholder perspectives. In particular, in terms of iGEM and synthetic biology, it provided insights into its culture, projects and material outcomes.

Exhibiting outcomes was challenging. In spite of having to postpone the UK exhibition, at least one proposed framework has emerged. However, there is a need for clearer regulations for exhibiting artworks involving GMOs. Providing a risk assessment was one way this research demonstrated that the works developed carried minimal risks to human health and the environment, although this may not be the case for other artworks involving GMOs. Exhibiting these works as living offers a more tangible sense of the life as it becomes increasingly enmeshed in technology. For curators and organisers wanting to include such works there is equally a need to appreciate the different parameters that come into play when exhibiting living matter often requiring special access and preparation. These variables provide a background to why artists often choose to exhibit documentation and conceptual objects rather than the living. This

research argues both through practice and theory that the presence of the living is key in exhibiting such artworks and documentation provides support but does not offer the level of immediacy needed to fully appreciate this art form.

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# Chapter 7
# Conclusion

This research develops a model of practice for artists to work with scientific methods to construct biological systems. Working with contemporary ideas of art and science (i.e. bio art and synthetic biology) involves many uncertainties. This research shows how artists can navigate between the domains of bio art and synthetic biology through a laboratory practice. Namely;

(1) It has adopted methods and understandings from the biosciences to transform intangible biological processes into tangible sensory expressions as artworks.
(2) It expands on existing bio art practices by investigating capacities and processes of living matter rather than a focus on metaphorical discourses, a common trope in the field. The research has sought to move beyond narrations about 'life' to generate works from within the biological.

In doing so, a lengthy engagement with the biosciences was necessitated involving complete immersion in laboratory work, scientific theory and material practice which has generated a number of contributions:

(C1) A framework that conceptualises approaches to making bio artworks specifically using synthetic biology and molecular approaches (Chapter 2-6);
(C2) Specific knowledge and interfaces that bridge human and non-human living systems (i.e. tapping into biological processes and extended capacities using molecular and synthetic biology approaches, Chapter 3-5);
(C3) An evidence-based art practice as methods for artists to both achieve, exhibit and critically evaluate art-science practices (Chapter 4);
(C4) The methodological argument that a serious engagement with living matter requires equally serious and "immersive" learning of the science within a laboratory environment for artists working in the field (Chapter 4);
(C5) A framework that enables exhibition of GMO artworks within public settings in the UK (Chapter 6); and
(C6) Publicly disseminate multi-layered outcomes (including a body of artworks, related documentation and participatory activities) (Chapter 3-6).

Drawbacks of this research and approach are:

1) An independent laboratory practice requires significant investment in terms of time and costs. In addition, there are inconsistencies in working with scientific materials.
2) Exhibiting living matter can involve complicated maintenance procedures and can be difficult to sustain over longer exhibition periods (e.g. over a week). Further, GMO artworks cannot readily be exhibited internationally, since regulatory frameworks vary across countries.
3) Biological processes are often slow requiring supplementary documentation. Communicating knowledge processes such as biological signification may be challenging (i.e. it may be suggested that the works are simply colouring with bacteria rather than exploring deeper connections of the living). Added to this, organisms such as bacteria may be an unfamiliar concept for audiences.
4) There are no public scientific protocols for presenting such matter to the public, thus working with invisible material on small scales requires artists to generate their own protocols, which comes with significant overheads.

Detailed explanations of these findings are given following chapter summaries and section 7.2.

## 7.1 Summary of thesis

The thesis began by establishing the intent for undertaking a research project that combined art and science using approaches from bioscience. It suggested that new opportunities had emerged within the biosciences (particularly in synthetic biology) that could allow an artist to expand bio art practices by engaging with new capacities in bio media. An overview of the research project, its chapters, propositions and findings provided a grounding to initiate these debates (Chapter 1).

The contextual review revealed key characteristics that situated this research within bio art (Chapter 2). While the status of bio art remains uncertain given its sporadic history and limited set of artworks, the field has seen a growing interest in recent years (Section 2.1). The review drew a distinction between traditional and modern biotechnology suggesting that much of the field is situated in modern practices (Section 2.2). With a plurality of terms (i.e. transgenic art, genetic art, etc.) used to describe biological art practices, the subject area is evolving and lacks clear boundaries; bio art can therefore be thought of as an umbrella term for art practices involving the biosciences (Section 2.3). Most scholars have pointed to Steichen as the first recognised practitioner, leaving a fifty-year gap before the later work of Gessert and Davis.

During the late 1990s, controversies in the biosciences were swept by media frenzy leading numerous artists to respond to thematic and ethical issues but which also included those embarking on actual use of bio matter in their practices (Section 2.4). Today, the field has seen a steady increase in practitioners much indebted to workshops, academic courses, exhibitions and competitions. The literature on bio art mostly consists of essay collections and exhibition catalogues with academic writing tending to focus on issues of ethics. The limited literature may hint as to why there are many uncertainties in the field and underlines the need for more voices to debate this area of art (Section 2.5).

Much of bio art's theoretical debates are concerned with the use of media and examine how manipulation of bio matter have ethical implications that critique biosciences' utilitarian approach (Chapter 3). Bio art has seen a shift from a thematic representation and narratives concerned with the post-biological (e.g. genetics, tissue culture, etc.) towards material practices exploring the staging of living matter; indeed, the actual presence of the living is seen as an aesthetic component in bio art. In spite of this, the role of living material often remains problematised. This research argues that current approaches focus on issues of ethics, cultural meanings and hermeneutics that places the presence of living matter at a distance to itself. Thus the research suggested a need to explore actual biological processes through an independent approach focused on material investigation in a laboratory setting (Section 3.1).

The use, manipulation and caring for living matter in bio art practices encroach on ethical issues leaving it subject to critique[118]. While there are no agreed ethical positions amongst bio artists, numerous approaches are useful to consider, such as deontological, utilitarian and environmental (Section 3.2). This research aimed to both produce and publicly stage living GMO artworks requiring a pragmatic approach to deal with formal issues of regulations that involved obtaining ethical approval and negotiating the process with a government agency.

As argued in Chapter 3, the research needed to integrate scientific methods to achieve its outcomes. Chapter 4 debated strategies for adopting scientific methods in artistic practices outside of collaborative models that employed scientists. It suggested that tapping into biological processes and capacities in bacteria using synthetic biology required formal scientific settings and an immersive laboratory practice as an appropriate method for such undertakings. By developing learning mechanisms and undertaking a lengthily investment in adopting scientific material and

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[118] For example, Virilio has pointed to extreme examples involving genetic manipulation of humans as art, however, most bio artists see this a far-fetched proposition that would require ethical attitudes to be re-evaluated throughout society (Section 3.2).

methods, the research was able to apply these towards artistic outcomes (Section 4.1-4.8). Using synthetic-, molecular- and microbiology allowed the research to work on levels of genetic components and bacteria, and established a rich set of methods, materials and understandings. The use of documentation and reflective processes helped guide the technical undertakings and evaluation of expressions towards tangible and experiential phenomena (Section 4.9-4.15). To harness biological expressions, capacities and reproducibility, an evidence-based practice provided the glue needed for the material layering processes that included preparation, production and finally exhibition of such matter (Section 4.16).

Chapter 5 sought to direct methods, material and the artistic inquiry towards production of outcomes. It also provided answers to how artists could engage with biological knowledge on more profound levels and how it could broker understandings of non-human living organisms (Section 5.1). Being situated in a scientific laboratory with commensurate material struggles informed the research with a wealth of primary data, reflective processes helped organise this material into usable research and helping direct the practice (Section 5.2).

A common theme in all works was potentials in growth and processes of change. First, by exploring bacterial patterns using information simulation (*Bacterial World*, Section 5.3), followed by looking at growth as behaviour (Section 5.4) and leading into experiments with chemotaxis (*Sugar Rush*, Section 5.5). A major work involved visualising changing states in bacteria by constructing a genetic system that expressed GFP in response to oxidative stress (*katE*) and later a red fluorescent construct (*katE-RED)* allowing visualisation of stress on swarming-plates (Section 5.6). Based on this initial work, a large-scale visualisation display was created to capture and modulate stress in bacteria as light (*Stress-o-stat*, Section 5.7). The use of synthetic biology also enabled exploration of several new biological methods, such as a genetic system capable of converting an alcohol into a banana smelling ester towards an olfactory public display (*Banana Bacteria*, Section 5.8), and an oscillation system that toggles (i.e. on/off) production of fluorescent proteins in bacteria at intervals (*Tick-Tock Bacteria*, Section 5.9). A good portion of time was spent building and extending a light-sensing system in *E. coli* towards a work (*Bacterial Light Sensor*) that could express fluorescent protein in response to external light activation (Section 5.10). Another work involved using magnetotactic bacteria to form images using a computer controlled magnetic array (*Living Mirror*). The work was awarded the Designers and Artists 4 Genomics Award (2013) for further realisation (Section 5.11). Using nanomagnetic particles with *E. coli* produced interactive potentials by allowing bacteria to be manipulated using a strong magnet (*Bacteria Compass*, Section 5.12). The research also built a few tools to aid the documentation

process (*Growth Chamber*, Section 5.13) such as time-lapse recordings. This was useful in capturing degradation of textile-dye by sewage bacteria where a matrix of bottles was used to form appearing and disappearing images (*Transient Images*, Section 5.14). Given that these processes were evidence-based (i.e. confirmed material prediction towards construction), the supporting information adds an additional layer as do the visualisations of biological processes that escape our senses in real-time (i.e. time-lapse, dyes and gels).

The main focus of Chapter 6 was to examine the issues faced when exhibiting GMOs publicly. With the practice shifting from production to staging outcomes, it became increasingly involved in public dissemination activities that informed the research in relation to synthetic biology (Section 6.1). The initial exhibition involving the GMO artworks *Stress-o-stat* and *Banana Bacteria* was halted due to worries that emerged via consultation with the Health and Safety Executive (HSE) that no records of previous GMO exhibitions could be obtained. Subsequent discussions with key stakeholders evidenced uncertainties surrounding these activities and in the UK artists had previously been stopped from displaying such works. The research negotiated a framework that enabled the first GMO exhibition in the UK by (1) applying and obtaining formal ethics approval and (2) liaised works, premises and risk assessments on a case-by-case scenario with the HSE (Section 6.2-6.3).

Given the UK-specific challenges, the first exhibition showcasing GMO artworks for this research took place in Mumbai, India at Techfest. The logistical challenge of putting this together involved transportation of material and reproducing the work in a local University laboratory, however, the exhibits and festival went ahead successfully with a great number of visitors (90,000 in three days) (Section 6.4). Following agreements with the HSE, two initial attempts to show these works in the UK broke down due to unjustified health and safety concerns. This underlined a need to enter into an early and informative debate around the whole process of exhibiting such artworks. Further, the final period of this research revealed a great deal of confusion amongst stakeholders in terms of understanding the regulatory status of various bio matter (i.e. human tissue versus GMOs) and suggested a need for curators and stakeholders to inform themselves in order for these activities to be staged in public settings.

## 7.2 Contribution

We should now be able to see how the intellectual signification is tethered to the research questions asked in Chapter 1 by pointing to interrelated challenges and findings in preceding chapters.

As stated, the research argued the need to renegotiate the use of living matter in bio art by taking into account biological processes and its extended capacities (e.g. introduced genetic expressions or capabilities in performing a bio-chemical tasks) (Chapter 3). Motivated by recent material opportunities emerging from synthetic biology, the research suggested a need to graft scientific methods onto the art practice. To achieve this, the research asked:

(RQ1) How can artists assimilate the recombinant affordances of bioscience towards art production and what critical issues are thrown up through such approaches?

As an independent research, it employed an immersive laboratory practice and evidence-based methods to appropriate molecular and synthetic biology leading to a series of outcomes (Chapter 4 and 5). Thus, the research involved a considerable investment in scientific knowledge processes needed to tackle uncertainties, material struggles and risks in working with living matter, and finally leading into challenges of publicly staging GMOs (Chapter 4, 5 and 6).

As a whole, the research contributes a framework for art practitioners to make bio artworks (C1) by laying bare processes within a rigorous research framework for the first time, and by making these mobile via written thesis and documentation. Its use of synthetic biology and molecular approaches provides a new arsenal of methods for bio artists to work with living matter in a structured, deepened and independent manner.

This research involved public dissemination of multi-layered outcomes, a layered contribution that includes a body of artworks, documentation and public debates (C6). It involved staging the first living synthetic biology exhibition in India and mobilising documentations (e.g. videos, photos, etc.) into portable formats for dissemination through conferences, exhibitions, and online and social media.

By formulating a deeper integration of scientific methods into art practice, the research suggested that artists concerned with bio matter might usefully focus their attention on exploring actual biological signification (Chapter 3) by asking:

(RQ2) What role can art practices play in brokering understandings of 'life' in non-human biological systems (e.g. bacteria)?

The practice's use of scientific methods provided a powerful platform to explore otherwise invisible processes (e.g. oxidative stress) in the living. It involved working on a genetic level to develop new capacities capable of generating telling experiences (Chapter 4 and 5). This type of mediation pushes bio art beyond metaphoric use of living matter. Art has a history of dealing

with life processes and 'making the invisible visible' that stretches into recent new media art (i.e. genetic algorithms), however, it was argued that these do not provide the same presence as having expressions emanating from within bio matter itself (Chapter 3). The research delivered a set of methods, approaches and outcomes (e.g. *katE*, *Stress-o-stat*) using genetic strategies that contributes new knowledge by generating specific processes and interfaces that bridge human and non-human living systems (C2) (e.g. that make the invisible tangible for human audiences). As discussed, the use of evidence-based practices played a central role to support insights that transformed intangible molecular processes into experiences. Bio matter as used in this research involved unobservable compounds that needed precise handling to generate predictable biological expressions. As these processes can be complex, a rigorous approach was needed and meant gathering, scrutinising and verifying evidence to support the construction of bio artworks. As an evidence-based art practice (EBAP), it involved layering documentation and production of material. Aligned with scientific practices, it used iterative processes enabling this research to stake claims in life-processes. Thus, this research was able to expand on bio art practices by utilising emerging material possibilities that could establish links between biological signification and experience (or presence).

(RQ3) What physical and biological interfaces could be devised to enable access to this knowledge?

Chapter 4 provided an extensive set of methods for the production of interfaces on a genetic level (e.g. fluorescent proteins). The adaptation of scientific methods together with an ongoing evaluation of materials and expressions generated both molecular interfaces (e.g. *katE*) and physical interfaces (e.g. *Stress-o-stat*) that accessed these knowledge processes. The research showed how the use of an immersive and evidence-based art practice as methods for artists offered approaches for achieving and critically evaluating art-science practices (C3 & C4).

(RQ4) What can be learnt from exhibiting living synthetic biology artworks and how are regulatory frameworks negotiated?

Chapter 6 showed that the issues faced exhibiting GMOs in the UK are substantial and require a formal framework to be established. Even so, discussions with stakeholders and curators showed that there is limited awareness of how different bio matter is regulated. Thus, the research contributes by generating a framework that enabled exhibiting GMO artworks within public settings in the UK (C5). It did so by deploying outcomes and artworks into formalised regulatory

documents enabling a framework for GMO artworks to be legally staged in the UK. In doing so, it allowed GMO artworks to be formally exhibited in UK for the first time.

### 7.3 Future scope

The research to date has contributed by providing conceptual, practical and methodological tools for working with bio art and synthetic biology. The investment in appropriating scientific methods was substantial but by gaining such mileage it has been possible to explore an increasingly complex use of materials and methods. While not all artworks could be achieved within the research, methods have been identified to achieve such propositions in forthcoming work. For instance, *Living Mirror* has already achieved funding to develop the work at science institutes and to be exhibited in a museum. In pursuing further possibilities through integration of scientific methods with art practice, the research aims to offer novel findings across the arts and science. One such exciting promise is the integration of digital and biological interfaces and it is this research frontier that will focus further work.

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# Appendices

The research involved a substantial set of scientific protocols normally accounted for in a scientific thesis through its material and methods. The appendix provides access to protocols, specific ethics approval and regulatory document needed for working with and exhibiting the material, and list of exhibitions. Protocols offer quantifiable procedures of what was done, and while protocols and kits will forever change with technology they demonstrate how work was done at this particular time. They may also provide an insight into how this type of art science practice engages in scientific practices on a somewhat equal level.

## Appendix I. Competent Cells

A variety of strains were prepared as heat-shock competent cells. This process involves making cells permeable by growing the culture to a specific optical density and doing a series of washing steps. The strains prepared as competent were: XL-1 Blue, DH5-alpha, Mach-1, JM101, JT-2 and RU1010. The following protocol was used in all preparation from 200 ml of cell culture.

Materials

LB medium (Appendix II.I) ..... 1000 ml
LB-agar plate (no-antibiotics) (Appendix II.II) ..... 1
1M $MgCl_2$ solution (Appendix V.II) ..... 100 ml
1M $CaCl_2$ solution (Appendix V.I) ..... 500 ml
50% glycerol solution (Appendix VI.II) ..... 10 ml
Falcon (centrifuge) tubes (50 ml) ..... 8
Microcentrifuge tubes ..... 80

Method

1. Incubate 10 µl of cell from the glycerol stock or pick 5 single colonies of cell from the LB agar into 10 ml of culture media containing no antibiotic or specific for the cell type. Grow the cultures overnight.

2. Inoculate 200 ml of pre-warmed medium (no antibiotics or specifics for the cell type) with 10 ml of the overnight cultures, and grow at 37°C for 60 min, with vigorous shaking 250 rpm, until the $OD_{600}$ is 0.4 - 0.5.

3. Put on ice for 30 min. At the same time chill sterile falcon (centrifuge) tubes.

4. Harvest the cells by centrifugation for 7 min at 3500 rpm, at 4°C and discard supernatants completely.

5. Resuspend cells in ¼ vol. of 0.1 M $MgCl_2$ (50 ml for 200 ml of cell culture).

6. Centrifuge for 7 min at 3500 rpm, at 4°C and discard supernatants.

7. Resuspend cells in ½ vol. of 0.1 M $CaCl_2$ (100 ml for 200 ml of cell culture).

8. Incubate cells on ice for 30 min.

9. Centrifuge for 7 min at 3500 rpm, at 4°C and discard supernatants.

10. Resuspend cells in 1/50 vol. of 0.1 M $CaCl_2$ + 15% glycerol (2.8 ml of 0.1 M $CaCl_2$ and 1.2 ml of 50% glycerol).

11. Final volume 4 ml.

12. Store in 50 µl aliquots at –80°C

## Appendix II. Media

### Appendix II.I. LB Medium

Also called: Lysogeny broth, Luria broth, Lennox broth or Luria Bertani Media

LB-medium is a rich medium and the industry standard for growing *E. coli*. It can be procured as a ready-mixed powder or made by mixing three sub-components.

To prepare 1L LB-medium:

Tryptone..... 10 g
Yeast extract ..... 5 g
NaCl..... 10 g

Alternatively, and mostly used in this research was a ready-mix (company name, product code) 32 g/L.

LB broth (Sigma) ..... 32 g

**Preparation:** Add distilled water for a final volume of 1 L, dissolves and autoclave at 121ºC for 15 minutes at 15 psi.

Appendix II.II. LB agar

LB agar is typically prepared using LB medium containing 15 g/liter agar.

Agar..... 15 g
LB medium (Appendix II.I)..... 985 ml (Final volume 1L)

Alternatively, it is possible to procure a ready-mix of LB-agar.

LB Agar (Sigma)..... 32 g
Distilled water ..... 968 ml (Final volume 1L)

**Preparation:** Dissolves and autoclave at 121ºC for 15 minutes at 15 psi.

Notable 15 g/L is equivalent to 15% (w/v or weight to volume) agar the standard hardness or softness of LB agar (Table 1). The viscosity of the agar affects bacteria's ability to swim or translocate across an agar plate.

| Type | Percentage of agar to medium |
|---|---|
| Normal | 1.5% |
| Soft | 0.6% |
| Hard | 3% |

Table 1: LB-agar hardness according to percentage of agar in the medium.

By combining soft and hard agar it is possible to produce a swarming plate where hard-agar is poured as a bottom layer and soft-agar as a top layer. The soft-agar allows bacteria to translocate faster and given continuous evaporation of water from the media, it eventually reaches into the harder-agar making it more difficult to swim.

Appendix I.I. Minimal media

Minimal media also known as M9 media was used is *Banana Bacteria* (5.8).

To prepare 200 ml of M9-media:

5xM9 Salt ..... 40 ml
0.2M Thiamine Chloride..... 1 ml
20% Glucose ..... 4 ml
10% Casaminoacids..... 4 ml

1M $MgSO_4$ ..... 400 µl
1M $CaCl_2$ ..... 20 µl
Sterile water ..... 150.6 ml (Final volume of 200 ml)

**Preparation:** All components are pre-sterilized and can be mixed using sterile conditions to make-up the final media.

Appendix II.III. Super optimal both (SOB)

To prepare 200 ml of SOB:

Trypton (2% w/v) ..... 5 g
Yeast Extract (½% w/v) ..... 1 g
NaCl ..... 0.1 g
KCl ..... 37.2 mg

**Preparation:** Add distilled water for a final volume of 200 mL, dissolve and autoclave at 121ºC for 15 minutes at 15 psi.

Appendix II.IV. Super optimal concentrate (SOC)

SOC is used to recover cells during heat-shock transformation.

To prepare 100 ml SOC:

Materials

SOB (Appendix II.III) ..... 50 ml
D-Glucose (1M) (Appendix VI.I) ..... 25 ml
$MgCl_2$ (1M) (Appendix V.II) ..... 25 ml
Sterile syringe (50ml) ..... 1
Sterile micro filter (0.22 µm) ..... 1
Sterile Microcentrifuge tubes ..... 100

Methods

1. Mix components into a sterile flask

2. Use a syringe to extract 50 ml solution and fix a 0.22 µm filter to the syringe.

3. Aliquot 1ml SOC to each of 90-100 Microcentrifuge tubes.

4. Store at -20ºC

Appendix II.V. *Magnetospirillium* Media

Also called: Medium 380

*Magnetospirillium gryphiswaldense* (DSM-6361) shipped in *Magnetospirillium* media.

To prepare 1L *Magnetospirillium* solution (Atlas, 2010: 995)

Materials

Vitamin solution (Appendix II.VII)..... 10 ml
Trace elements (Appendix II.VIII) ..... 5 ml
Fe(III) Quinate solution (Appendix II.VI) ..... 2 ml
Agar (for semi-solid agar) ..... 1.30 g
$KH_2PO_4$ ..... 0.68 g
Resazurin..... 0.5 mg
L(+)-Tartaric acid ..... 0.37 g
Succinic acid ..... 0.37 g
$NaNO_3$ ..... 0.12 g
Na-thioglycolate..... 0.05 g
Na-acetate ..... 0.05 g
Distilled water ..... 1000 ml

**Preparation:** Dissolve in distilled water each of the ingredients in the order given (except thioglycolate), adjust pH to 6.75 using NaOH, add thioglycolate and distilled water to give a final volume of 1000ml. Boil the solution for 1 minute.

Methods

**Liquid medium:**

1. Purge medium with $N_2$ gas for 10 min and dispense under the same gas atmosphere in anoxic vials to 1/3 of their volume.
2. Seal vials with screw caps and gas tight rubber closures.
3. Autoclave at 121°C for 15 min.
4. Before inoculation add thioglycolate from a 3% (w/v) solution, freshly prepared under $N_2$ and filter-sterilized.
5. Add sterile air (with hypodermic syringe through the rubber closure) to 1% O2 concentration in the gas phase.

**Semi solid medium:**

1. Purge medium with $N_2$ gas for 10 min. and dispense under same gas atmosphere 10 ml of agar containing medium per 16 x 150 mm anoxic screw cap tube.
2. After autoclaving, tubes may be stored at room temperature.
3. Prior to inoculation add thioglycolate from a 3% (w/v) solution, freshly prepared under $N_2$ and filter-sterilized.

4. Add sterile air (with hypodermic syringe through the rubber closure) to a concentration of 1% (v/v) in the vial and let equilibrate medium overnight in order to establish a redox gradient.

**Notes:**

Prior to inoculation media should be slightly pink in colour. Strongly reduced conditions will not support growth of the organism. Incubate tubes with semi-solid medium without agitation in an upright position.

During growth $O_2$ will be consumed, resazurin decolorized and the pH increase. Feed oxygen (by adding air) and succinic acid from sterile 0.05 M solution (to maintain pH below 7). If higher densities of magnetic cell are wanted, ferric quinate also has to be fed. For transfer use cell material, which has been concentrated at the glass wall of the culture vessel by means of a magnetic rod, attached outside.

Appendix II.VI. Ferric Quinate Solution

To prepare 100 ml of 0.01 M Ferric Quinate Solution

$FeCl_3$ x 6 $H_2O$ ..... 0.45 g
Quinic acid ..... 0.19 g

**Preparation:** Add Distilled water for final volume of 100 ml, dissolve and autoclave at 121°C for 15 min.

Appendix II.VII. *Magnetospirillium* vitamin solution

To prepare 1L Vitamin solution (Atlas, 2010: 995).

Biotin ..... 2 mg
Folic acid ..... 2 mg
Pyridoxine-HCl ..... 10 mg
Thiamine-HCl x 2 $H_2O$ ..... 5 mg
Riboflavin ..... 5 mg
Nicotinic acid ..... 5 mg
D-Ca-pantothenate ..... 5 mg
Vitamin B12 ..... 0.1 mg
p-Aminobenzoic acid ..... 5 mg
Lipoic acid ..... 5 mg

**Preparation:** Add vitamins, dissolve and filter sterilise using a syringe with a 0.22 μm filter.

Appendix II.VIII. *Magnetospirillium* Trace elements solution

To prepare 1L of *Magnetospirillium* trace elements (Atlas, 2010: 995) (derivative of Wolfe's mineral solution):

$MgSO_4$ x $7H_2O$ ..... 3.0 g
Nitrilotriacetic acid ..... 1.5 g
NaCl..... 1.0 g
$MnSO_4$ x $H_2O$ ..... 0.5 g
$CoSO_4$ x 7 $H_2O$ ..... 0.18 g
$ZnSO_4$ x 7 $H_2O$ ..... 0.18 g
$FeSO_4$ x 7 $H_2O$ ..... 0.1 g
$CaCl_2$ x 2 $H_2O$ ..... 0.1 g
$NiCl_2$ x 6 $H_2O$ ..... 0.03 g
$KAl(SO_4)2$ x 12 $H_2O$ ..... 0.02 g
$CuSO_4$ x $5H_2O$ ..... 0.01 g
$H_3BO_3$ ..... 0.01 g
$Na_2MoO_4$ x $2H_2O$ ..... 0.01 g
$Na_2SeO_3$ x $5H_2O$..... 0.3 mg

**Preparation:** First dissolve Nitrilotriacetic acid in 1000 ml of distilled water, then adjust pH to 6.5 with KOH**,** add minerals**,** and dissolve and autoclave at 121°C for 15 minutes at 15 psi.

Appendix II.IX. Flask Standard Media

Flask Standard Media (FSM) is an improved media solution to enable fermentation of *M. gryphiswaldense* (Heyen and Schüler, 2003).

To prepare 1 L FSM:

$KH_2PO_4$ ..... 0.1 g
$MgSO_4$ $7H_2O$..... 0.15 g
Hepes ..... 2.38 g
$NaNO_3$ ..... 0.34 g
Yeast extract ..... 0.1 g
Soy bean peptone..... 3.0 g
Trace elements (Widdel and Bak 1992)..... 1 ml
Potassium L-lactate..... 27 mM

**Preparation:** Iron was added before autoclaving as ferric citrate (100 μM) and the pH of the medium was adjusted to 7.0 with NaOH.

Appendix III.I. Minimal Basal Media

A semi-defined media consisting of separate components (Minimal Salt Media, Vitamin Solution, Trace elements, Casamino acids and Glucose) mixed in vials and sealed with butyl rubber stoppers and oxygen purged by flushing with nitrogen gas.

To prepare 100 ml minimal basal media:

Azo dye (methyl orange, 300 mg/l) ..... 3 ml
10% Casaminoacids ..... 1 ml
(As an alternative to Casaminoacids:
Tryptone (500mg/l) ..... 50 mg)
Vitamin solution (Appendix II.II) ..... 1 ml
Mineral solution (Appendix II.III) ..... 1 ml
10% Glucose (100g in 1000ml water) ..... 2 ml
Minimal Salts Base Solution (Appendix II.I) ..... 92 ml

**Preparation:** Purge with $N_2$ for 10 minutes and inoculate with 10% culture

Appendix II.I. Minimal Salts Base Solution

The Minimal Salts Base Solution was built on 10mM phosphate buffer comprising of 4.22 mM NaH2PO4 and 5.99 mM Na2HPO4:

NH4Cl ..... 460 mg
K2HPO4 ..... 225 mg
MgSO4 x 7H2O ..... 117 mg
(NH4)2SO4 ..... 225 mg
Distilled water ..... 1000 ml

**Preparation:** Add salts, dissolve, and adjust pH to 7. Autoclave at 121ºC for 15 minutes at 15 psi.

Appendix II.II. Vitamin solution (100x)

The following vitamin solution (Wolin et al., 1963) used for minimal salt media:

P-aminobenzoic acid (PABA) 0.05 ..... 50 mg
L-ascorbic acid ..... 100 mg
Folic acid ..... 50 mg
Riboflavin ..... 10 mg
Nicotinic Acid ..... 100 mg
Pantothenic acid (sodium salt) ..... 100 mg
Thiamine ..... 100 mg
Botin ..... 100 mg
Distilled water ..... 1000 ml

**Preparation:** Add vitamins, dissolve and filter sterilise using a syringe with a 0.22 μm filter.

Appendix II.III. Mineral solution

The following mineral solution (Marsili et al., 2008) used for minimal salt media:

NTA (Nitrilotriacetic acid) ..... 1500 mg
MnCl2 x 4H2O ..... 100 mg
FeSO4 x 6H2O ..... 300 mg
COCl2 x 6H2O ..... 170 mg
ZnCl2 ..... 100 mg
CuSO4 x 5H20 ..... 40 mg
KAl(SO4)2 x 12H2O ..... 5 mg
H3BO4 ..... 5 mg
NaMoO4 ..... 90 mg
NiCl2 ..... 120 mg
NaWO4 x 2H2O ..... 30 mg
Na2SeO4 ..... 100 mg
Distilled water ..... 1000 ml

**Preparation:** Add minerals, dissolve and autoclave at 121ºC for 15 minutes at 15 psi.

Appendix II.IV. Seawater Complete (SWC) media

SWC is used to cultivate the auto-bioluminescent organism *Vibrio fischeri*. To prepare 1 L SWC:

NaCl ..... 24 g
Peptone ..... 5 g
Yeast extract ..... 3 g
Glycerol ..... 3 ml
Agar (if solid media) ..... 15 g

**Preparation:** Add distilled water to a final volume of 1 L, dissolve and autoclave at 121ºC for 15 minutes at 15 psi.

Growth condition for *Vibrio fisheri* is 21ºC.

## Appendix III. Antibiotics

Several different types of antibiotics where used through out the research as a negative selection method (i.e. allowing growth for only specific cells containing plasmids capable of degrading these chemicals). In some cases multiple antibiotics where used in combination to increase specificity. The table below (Table 2) provides a summary of colour coding and concentrations used.

| Antibiotics | Colour code | Stock concentration (freezer) | Final concentration | Use in 10ml | Use in 200ml |
|---|---|---|---|---|---|
| Ampicillin (Amp) | | 100 mg/ml | 100 µg/ml | 10 µl | 10 µl |
| Carbenicillin (Car) | | 50 mg/ml | 100 µg/ml | 20 µl | 10 µl |
| Chloramphenicol (Chl) | | 34 mg/ml (in ethanol) | 25 µg/ml | 7.5 µl | 10 µl |
| Kanamycin (Kan) | | 10 mg/ml | 50 µg/ml | 50 µl | 1 ml |
| Streptomycin (Stre) | | 10 mg/ml | 50 µg/ml | 50 µl | 1 ml |
| Tetracycline (Tet) | | 12.5 mg/ml (in 50% ethanol) | 12.5 µg/ml | 10 µl | 200 µl |

Table 2: Summary of concentration use various antibiotics use in media.

Appendix III.I. Kanamycin stock

To prepare 10 tubes of 1 ml (1,000x) Kanamycin stock.

- Weigh out 0.5 g Kanamycin powder (50 mg/ml) [50 mg/ml x 10 ml = 500 mg = 0.5 g]
- Add 10 ml distilled water.
- Use a syringe and a microfilter (0.22 µm) and aliquot 1 ml solution in each of 10 Microcentrifuge tubes.
- Mark the tube lids with a thick blue line.
- Store at -20ºC.

Appendix III.II. Chloramphenicol stock

To prepare 10 tubes of 1 ml (1,000x) Chloramphenicol stock.

- Weigh out 340 mg Chloramphenicol powder (34 mg/ml) [34 mg/ml x 10 ml = 340 mg]
- Add 10 ml absolute ethanol.
- Use a syringe and a microfilter (0.22 µm) and aliquot 1 ml solution in each of 10 Microcentrifuge tubes.

- Mark the tube lids with a thick green line.
- Store at -20ºC.

Appendix III.III. Ampicillin stock

To prepare 10 tube of 1 ml (1,000x) Ampicillin stock.

- Weigh out 1 g Kanamycin powder (100 mg/ml) [100 mg/ml x 10 ml = 1 g]
- Add 10 ml distilled water.
- Use a syringe and a microfilter (0.22 μm) and aliquot 1 ml solution in each of 10 Microcentrifuge tubes.
- Mark the tube lids with a thick red line.
- Store at -20ºC.

**Appendix IV. Inducer**

Appendix IV.I. X-gal and IPTG for blue-white screening

X-gal is a lactose analogue commonly used in cloning as a visual indicator to see if cells express β-galactosidase enzymes. If they do, X-gal converted into a blue product, and the technique is therefore sometimes referred to as blue-white colony screening. The principle uses α-complementation whereby a gene (*lacZα*) in the plasmid (e.g. pUC19, Bluescript) and genome (lacZΔM15) of cells (e.g. DH5-α) are co-expressed to form β-galactosidase. In the case of multiple cloning sites, a fragment can be inserted into a plasmid disrupting expression of *lacZα* gene this resulting in white colonies showing the successful uptake of the fragment or ligation.

To 200 ml X-gal / IPTG media:

IPTG (0.1 M final concentration) ..... 200 μl
X-gal (40 μg/ml final concentration)..... 400 μl
Petri dishes (25 ml per plate) ..... 8

**Preparation:** Incorporate X-gal (and IPTG) into plate before pouring or when temperature is less than 65ºC.

**Note:** X-gal is a light and heat sensitive product, thus both stock and plates must be stored in the dark to avoid this product to breaking down. An alternative dye, S-gal provides a more even

colour and is a more robust version since it can be autoclaved, microwaved and is not light sensitive.

## Appendix V. Buffers

Appendix V.I. Calcium Chloride solution

Calcium chloride is used in the artificial production of competent cells by making the cell membrane more permeable.

To prepare 100 ml 1 M Calcium Chloride:

$CaCl_2(H_2O)_6$ (219.1 g/mol) ..... 0.219 g
Distilled water ..... 100 ml (Final volume 100ml)

To prepare 500 ml of 0.1 M Calcium Chloride

$CaCl_2(H_2O)_6$ (219.1 g/mol) ..... 11 g
Distilled water ..... 489 ml (Final volume 500ml)

**Preparation:** Dissolve and autoclave at 121ºC for 15 minutes at 15 psi.

Appendix V.II. Magnesium Chloride solution

To prepare 100 ml 1 M Magnesium Chloride:

$MgCl_2(H_2O)_6$ (203.31 g/mol) ..... 0.2033 g
Distilled water ..... 100 ml (Final volume 100 ml)

To prepare 500 ml of 0.1 M Magnesium Chloride:

$MgCl_2(H_2O)_6$ (203.31 g/mol) ..... 10.2 g
Distilled water ..... 490 ml (Final volume 500 ml)

**Preparation:** Dissolve and autoclave at 121ºC for 15 minutes at 15 psi.

## Appendix VI. Carbon sources

Appendix VI.I. Glucose

Also known as: D(+)-Glucose, dextrose or grape sugar.

Glucose is a standard carbon source of *E. coli*.

To prepare 100 ml 0.1 M Glucose:

$C_6H_{12}O_6$ (180.16 g/mol) ..... 0.18 g
Distilled water ..... 100 ml (Final volume 100 ml)

**Preparation:** Dissolve and autoclave at 110ºC for 10 minutes at 15 psi (Higher temperature will caramelize sugars).

Appendix VI.II. Glycerol solution

Preparation 100 ml of 50% glycerol solution.

Glycerol ..... 50 ml
Distilled water ..... 50 ml (Final volume 100 ml)
Universal tubes ..... 10

**Preparation:** Dissolve, distribute in 10 Universal tubes and autoclave at 110ºC for 10 minutes at 15 psi (Higher temperature will caramelize sugars).

**Appendix VII. Agarose gel**

Common separation of DNA fragments use either 1% or 2% agarose gels. The gel is a mixture of a gel forming powder (agarose) and a Tris-Acetate-EDTA buffer (TAE). The hardness of the gel (higher-percentage) is used to capture DNA fragments of various sizes. A 1% gel is commonly used to capture fragments ranging from 1000-10000 bp and a harder gel of 2% separate smaller fragments in the range 100 bp-1200 bp.

Materials

- 1xTAE (stock solution is 50x, so 20 ml 50xTAE in 980 ml distilled water yield 1 L 1xTAE)
- Agarose powder (Sigma, Product no)
- Ethidium Bromide (Safety note! Carcinogenic substance)
- Gel tray
- Autoclave or masking tape
- Gel comb
- Gel tanks
- Powerpack with ability to regulate voltage, current and timing.

Methods

1. A gel tray is prepared by using either masking or autoclave tape. (Autoclave tape is preferred as it is stronger and more heat resistant but also more costly)

13. Tape the gel tray on the open front and back by allowing the lining of the tape to form a seal at the bottom and side. The tape should be tall enough for the tray to fit 70 ml of solution.

14. Fit the comb into slots at the front or back of the tray.

15. Prepare 60 ml of 1% agarose gel by weighing out 0.6 g agarose powder (for 2%, 1.2 g), add to an Erlenmeyer flask (either 100 or 200 ml) and cover using a sponge stopper.

16. Add 60 ml of 1xTAE

17. Mix-well by swirling ensuring no clumps (these will form aggregates if heated)

18. Heat slowly until it boils by mixing at intervals

19. Once solution is transparent with no visible particles allow the solution to cool until hand can be held at the base for 10 seconds without burning

20. Add 1 µl of Ethidium Bromide. Note: Alternatively place the gel in an Ethidium Bromide bath for 10 minutes after DNA separation.

21. Pour gel slowly into a prepared gel tray to avoid any bubble formation. Note: Formation of bubbles can be removed using a pipette tip by slowly guiding these to the corners of the gel. Since a 2% gel sets faster it needs faster handling to avoid bubbles.

22. Wait until the gel sets (approx. 45 minutes).

23. Remove the comb by gently but rapidly pulling it straight up. Note: The point here is not to distort the wells and ensure these are even and rectangular.

24. Remove tape and place into the fitted slots of a gel tank ensuring that wells are closest to the negative electrode (e.g. marked black).

25. Pour 1xTAE into the tank in order to submerge the gel ensuring that all wells are flooded.

26. Fix the tank lid and connect leads to Powerpack by ensuring right polarity.

27. Set the Powerpack to 100 V constant for 1 hour and run gel.

## Appendix VIII. Transformation method

Transformation using heat shock was used through out the research and is done to enable bacteria cell to take up foreign plasmid DNA. An alternative method suggests using electro shock.

Material

- SOC – 250 µl (Appendix II.IV)
- LB-agar plates with appropriate antibiotics
- Competent cells (e.g. XL1-Blue, DH5-alpha) (Appendix I)
- Plasmid (e.g. pMAK-512) with antibiotic cassette or a ligation solution
- Ice
- Sterile glass beads
- Bunsen burner
- Waterbath 42 ºC
- Microcentrifuge tube sponge holder
- Incubation shaker

Methods

1. Preheat 250 µl SOC in incubator to 37 ºC (i.e. 10 minutes)

2. Preheat fresh LB-agar plates with antibiotics by placing upside down and slightly open in a 37 ºC incubator to ensure no damp or droplets on lid

3. Collect 1 tube of 50 µl competent cells from -80 ºC freezer storage

4. Allow thawing for 5 minutes

5. Add 1 µl of plasmid DNA or 10 µl ligation solution

6. Wait for 5 minutes

7. Place in floating foam tube rack and place in 42 ºC waterbath for exactly 1 minute

8. Place back on ice for 5 minutes

9. Add 250 µl SOC and mix-well

10. Fix in incubator shaker for 1hr at 37 ºC using 250 rpm.

11. Working close to flame, pour or pipette transformant solution in the middle of plate.

12. To spread, add 6-10 glass beads and shake gently for 2 minutes or until all liquid is set and distributed.

13. Remove glass beads by gently pouring into a flask (these can be autoclaved and used again).

14. Annotate petri dish by writing the name, date, strain and plasmid around the circumference of the base.

15. Place plate upside down in an incubator at 37 ºC for 16 hours

## Appendix IX. DNA Miniprep

Two commercial miniprep kits were used in this research, Invitrogen S.N.A.P. and QIAgen Miniprep kit. The majority of the research used QIAgen Miniprep kits making it the most relevant to describe. The protocol commonly used in our laboratory was a slightly modified from the suggested commercial protocol (QIAgen, 2006).

Materials

- P1 resuspension buffer with RNase (on ice, stored at 4 ºC) in addition LyseBlue was added as an indicator for lysis.
- P2 lysis buffer
- N3 neutralisation buffer
- PB washing buffer
- PE washing buffer (prepared with ethanol)
- Spin-columns with filter
- 5-10 ml overnight culture

Method

1. Place and balance DNA samples in centrifuge

2. Spin at x6,400 g for 10 minutes to separate cell pellets from media

3. Remove supernatant (media) and place on ice

4. Resuspend cell pellets in 250 µl P1 buffer (with RNase) until no lumps and transfer to microcentrifuge tube (1.5 ml)

5. Add 250 µl P2 Lysis buffer and wait for 3-5 minutes, the solution should turn blue (mix very gently as too much may cause shearing genomic DNA leading to blocked filters or streaks in gel bands)

6. Add 350 µl N3 Buffer and mix by inverting tubes, the solution will being to precipitate

7. To separate plasmid from cell components, centrifuge at 13,000 rpm for 10 minutes

8. Transfer supernatant to clean filter column by decanting or pipetting (ensure now clumps are transferred)

9. To bind, centrifuge at 13,000 rpm for 1 minutes

10. Add 500 µl PB buffer, to help remove nuclease (XL-1 Blue and DH5-alpha do not require this step).

11. To wash, centrifuge at 13,000 rpm for 1 minutes and remove flow-through

12. Add 750 µl PE buffer

13. To wash, centrifuge at 13,000 rpm for 1 minutes and remove flow-through

14. To remove trace of alcohol, centrifuge at 13,000 rpm for 1 minutes and remove flow-through

15. Place filter in an empty microcentrifuge tube

16. Add 30 µl of nuclease free water and wait for 1 minute

17. To elute, centrifuge at 13,000 rpm and remove filter

18. Label tube and store at -20 ºC

**Appendix X. Gel extraction**

Two commercial gel extraction kits were used in this research, Invitrogen S.N.A.P. and QIAgen Gel Extraction Kit. As with the miniprep kits (Appendix IX) the preferred brand was QIAgen and involved only slight modification to the commercial protocol (QIAgen, 2010).

Materials

- QG Buffer
- PE washing buffer (prepared with ethanol)
- Isopropanol (10%)
- Spin-columns with filter

Method

1. After verifying the desired band, excise using a clean scalpel from the agarose gel

2. Place band in microcentrifuge tube and label

3. Add 300 µl of QG buffer (or 3x volume of gel) for 1% gel and double for 2%

4. Incubate at 50 ºC for 10 minutes and vortex at intervals ensuring all gel is dissolved

5. Check colour is yellow (if orange or violet add 10 µl 3 M sodium acetate)

6. Add 100 µl isopropanol (or 1x volume of gel) and mix well

7. Pour content into a 2 ml filter with collection tube

8. To bind, centrifuge at 13,000 rpm for 1 minute remove flow-through

9. Add 500 µl QG buffer

10. Centrifuge at 13,000 rpm for 1 minute remove flow-through

11. Add 750 µl PE buffer

12. To wash, centrifuge at 13,000 rpm for 1 minute and remove supernatant

13. To remove trace of alcohol, centrifuge at 13,000 rpm for 1 minute

14. Place filter in an empty microcentrifuge tube

15. Add 30 µl of nuclease free water and wait for 1 minute

16. To elute, centrifuge at 13,000 rpm and remove filter

17. Label tube and store at -20 ºC

## Appendix XI. Colony PCR

Colony PCR was used in many instances. The most common use was to check an assembly for a particular insert. It can also be used to extract material from the genome or plasmids.

A common and useful example to illustrate this method is checking or extracting a Biobrick™ using standard Biobrick™ primers VR and VF2.

Obtaining the colony mixture:

Colony ..... 1
$_{dd}H_2O$ (HPLC) ..... 10 µl

**Preparation:** Pick a colony, using a loop or a pipette tip. Elute the colony with 10 µl HPLC water in a microcentrifuge tube.

## Appendix XII. Digestion

Appendix XII.I. Biobrick™ RFC-10 enzymes

Although this research used a variety of restriction enzymes, its involvement with Synthetic Biology standardisation RFC-10 required a specific set of enzymes:

| Enzyme | Sequence | Buffers | Inactivation Temperature |
|---|---|---|---|
| EcoRI | 5'…G/AATTC…3'<br>3'…CTTAA/G…5' | #1: 100%<br>#2: 100%<br>#3: 100%<br>#4: 100% | 65 ºC for 20 minutes |
| EcoRI-HF™ | 5'…G/AATTC…3'<br>3'…CTTAA/G…5' | #1: 10%<br>#2: 100%<br>#3: 0%<br>#4: 100% | 65 ºC for 20 minutes |
| XbaI | 5'…T/CTAGA…3'<br>3'…AGATC/T…5' | #1: 0%<br>#2: 100%<br>#3: 75%<br>#4: 100% | 65 ºC for 20 minutes |
| SpeI | 5'…A/CTAGT…3'<br>3'…TGATC/A…5' | #1: 75%<br>#2: 100%<br>#3: 25%<br>#4: 100% | 80 ºC for 20 minutes |
| PstI | 5'…CTGCA/G…3'<br>3'…G/ACGTC…5' | #1: 75%<br>#2: 100%<br>#3: 25%<br>#4: 100% | 80 ºC for 20 minutes |

Appendix XII.II. Single Digest

A single digest is commonly used to check the size of a plasmid by making the circular plasmid linear allowing the DNA size to be determined on an agarose gel.

Example of a 50 µl reaction using EcoRI-HF:

EcoRI-HF ..... 1 µl
1xBuffer #4 ..... 1 µl
100xBSA ..... 0.5 µl
DNA ..... 30 µl
$_{dd}H_2O$ (HPLC water) ..... 12.5 µl (Final volume 50 µl)

**Preparation:** Add all reagents and solvents to a microcentrifuge tube and incubate for 1 hour at 37 ºC.

Appendix XII.III. Double Digest

A double digest is more common when preparing DNA assembly.

Example of a 50 µl reaction using EcoRI-HF with XbaI (i.e. upstream Biobrick™ backbone):

EcoRI-HF ..... 1 µl
XbaI ..... 1 µl
1xBuffer #2 ..... 1 µl
100xBSA ..... 0.5 µl
DNA ..... 30 µl
$_{dd}H_2O$ (HPLC water) ..... 12.5 µl (Final volume 50 µl)

**Preparation:** Add all reagents and solvents to a microcentrifuge tube and incubate for 1 hour at 37 ºC.

Common Biobrick™ double digests.

**Upstream insert:** EcoRI-HF™ + SpeI, Buffer #2, BSA

**Downstream insert:** XbaI + PstI, Buffer #2, BSA

**Upstream backbone:** EcoRI-HF™ + XbaI, Buffer #2, BSA

**Downstream backbone:** SpeI + PstI, Buffer #2, BSA

Appendix XII.IV. Serial Digest

A serial digest was used in this research to tackle difficult digestions.

Appendix I.I. 3A-digestion

An A3 digest was used in this research for 3A-assembly. This methods gets around idempotent assembly by avoiding gel purification by using a different hosting backbone to those arriving from relevant inserts (Rettberg et al., 2011).

For instance, the following digest must first be prepared and heat-inactivated. For solution 3, in addition to using EcoRI and PstI this reaction will also use DpnI in order to remove any residual none-linearised backbones. It makes no difference if these inserts (solution 1 and 2) are generated by plasmids or amplified using a PCR reaction.

Solution 1: E — Part A — S | E — Backbone A (Amp) — S

Solution 2: X — Part B — P | X — Backbone B (Amp) — P

Solution 3: E — Receiving Backbone (Kan) — P

(For ligation of the parts see Appendix XIII.II)

Appendix XII.V. DNA phosphorylation

Shrimp alkaline phosphatase (SAP) is used to remove sticky ends from vectors and prevent self-ligation.

SAP (1unit/µg DNA)..... 28 µl
DNA backbone (100ng/µl)..... 4 µl
10x SAP Buffer ..... 5 µl
$_{dd}H_2O$ (HPLC water) ..... 13 µl

**Preparation:** Mix components in a sterile microcentrifuge tube to a final reaction of 50 µl. Incubate at 37 ºC for 15 minutes. Deactivate SAP enzymes by heating inactivating for 15 minutes at 65 ºC.

Appendix XII.VI. Heat inactivation of enzymes

Inactivates enzymes and can be used in PCR reactions to overcome need for gel purification and in idempotent assembly is used as a standard method to skip use of agarose gel.

## Appendix XIII. Ligation

Appendix XIII.I. Standard Ligation

Ligation was used to combine compatible DNA fragment by means of enzymatic repair. The enzyme is added to a buffer solution with the DNA fragment, incubated at room temperature

and transformed into competent cells to yield a new DNA composite. In order for this to happen the DNA fragments consists of a backbone (containing origin of replication and antibiotic cassettes) and an insert.

For a 10 μl ligation reaction

Ligase (1unit/μg DNA) ..... 1 μl
Ligase buffer (10x)..... 1 μl
DNA Insert..... 7 μl
DNA Backbone ..... 1 μl

**Preparation:** Mix components in a sterile microcentrifuge tube to a final reaction of 10 μl. Incubate at room temperature for 1 hour. Proceed to transform the solution.

**Note:** Many commercial companies suggest a much shorter ligation time can be used depending on the quality and quantity of the DNA material. For instance, NEB suggests that their ligase can complete this reaction in as little as 5 minutes. The protocol laboratory practice common amongst other researchers in my laboratory suggested a standard time was better than attempting to minimise the reaction period.

Appendix XIII.II. 3A-Ligation

Combining using the following reaction of 10 μl volume:

Solution 1 (upstream part)..... 2 μl
Solution 2 (downstream part) ..... 2 μl
Solution 3 (receiving backbone) ..... 2 μl
10x T4 DNA Ligase Buffer..... 1 μl
T4 DNA Ligase..... 0.5 μl

**Preparation:** Add all reagents to a microcentrifuge tube and incubate for 2 hour at room temperature. Proceed to transform entire reaction on hosting antibiotics (e.g. Kanamycin) otherwise described in Appendix VIII.

**Note:** This reaction will not resolve in a giant backbone nor close up existing reaction. Existing backbones and insert will not yield colonies since these do not infer antibiotic resistance. A giant assembly of backbones is highly unlikely and it has been estimated that 97% of colonies contain the correct insert.

## Appendix XIV. Cryopreservation of cells

To preserve culture for long-term storage a glycerol stock was taken from a growing culture and stored at -80 ºC. In some cases storage at -20 ºC was done for short period but this may affect the viability of the culture.

Glycerol (50%) ..... 300 µl
Culture ..... 700 µl

**Preparation:** Mix components in a sterile microcentrifuge tube to a final reaction of 1 ml. Label and store at -80 ºC for an indefinite time.

## Appendix XV. Streaking plates

To obtain single colonies a technique known as streaking was used whereby either a disposable plastic loop or a metal loop is dipped in a culture and gently spread out on an LB-agar plate in a consistent manner.

Material

LB-agar plate ..... 1
Culture ..... 1
Loop ..... 1

Method

1. Dip a sterile loop in the culture
2. Without breaking into the agar, gently streak from the edge in a criss-cross fashion half-way towards the centre
3. Turn the plate 90 degrees and begin streaking from the last line half-way towards the centre without crossing over pervious lines
4. Repeat again
5. Finally, streak all the way into the centre

## Appendix XVI. Vacuum dry plasmid pellets

Used to increase concentration of a plasmid elution. The machine consists of: (a) Pump or dryer, (b) Vacuum pump, (c) Centrifuge and (d) Vacuum release.

Materials

- One or several plasmid purifications
- A vacuum drying machine

Method

1. Place and balance samples in centrifuge

2. Switch on: close (d), switch on (a), switch on (c) and switch on (b).

3. Wait for 20 minutes to convert 120 µl to 30 µl

4. Switch on: switch off (c), switch off (b), open (d) and switch off (a).

**Appendix XVII. Measuring optical density (O.D.)**

To establish the density and phase of a cell culture a spectrometer fitted with a cuvette port can be used to produce a measurement of the optical density. The spectrometer is first calibrated with a blank sample that is the media used without any culture and then compared with the reading of a sample containing the culture. For *E. coli* the doubling time in ideal conditions is about every 20 minutes thus timing of measurements must be done punctually. The reading is done using a laser at a specific wavelength. In all cases a wavelength of 600 nm (or white light) was used in measurements procedures.

Material

Cuvette ..... 1 (at least)
Culture ..... 1 batch (e.g. 10 ml to 200 ml)
Media ..... 1 batch (e.g. 10 ml)

Method

1. Switch on the spectrometer and set the wavelength to 600 nm

18. Add 1ml of clean media to a cuvette and place in port with arrows of cuvette and port symbol pointing the same way

19. To calibrate press 'set ref' and remove the cuvette

20. Add 1 ml of culture to an empty cuvette and place in port

21. A measurement should be digitally provided

Common O.D. numbers (*E. coli*)

Preparation of competent cells ..... 0.5-0.6
Preparation of protein purification ..... 0.6
Overnight growth for DNA purification ..... 1

## Appendix XVIII. Nanodrop – DNA quantification

To quantify DNA in terms of weight per volume and purity, a laser spectrometry analysis using a Nanodrop machine provides a way for obtaining such measurement from a single droplet of DNA solution. The spectrometer is connected to a computer via a USB cable and accompanied software provides an interface to control calibration and specific templates of reading according to the type of matter (e.g. DNA, RNA or proteins). The data produced are essential for precise quantification prior to sequencing, however, rough estimates can be made by gel analysis.

Material

Purified DNA (plasmid or PCR product) ..... 10 µl (at least)
$_{dd}H_2O$ (HPLC water) ..... 10 µl (at least)
Filter drying paper ..... 1 box

Method

1. Switch on the system (computer and Nanodrop machine) and open the software.
2. Select DNA 210/280.
3. Open the lever on the spectrometer and gently clean the glass.
4. Add 1 µl of HPLC water to the glass reader (make sure that it is not touched with the pipette).
5. Close the lever and select calibrate (a short clicking sound is heard).
6. Open the lever and gently clean of the drop before adding 1 µl of DNA.
7. Using the software, select sample and name the sample accordingly.
8. Clean and repeat until all samples, make notes on a separate paper, the tube or print the data upon finishing (e.g. sample #1, 55 ng/µl, 210=1.94, 280=1.86).

## Appendix XIX. Manual autoclaving

While technicians normally performed autoclaving, several occasions and also outside my own laboratory (i.e. during the exhibition at Techfest) required knowing how to do manual autoclaving. The normal machines used for this type of work are Stovetops similar in many ways

to pressure cookers. Most of these machines have a single temperature/pressure (121 ºC/15 psi) setting and have a security valve, a pressure valve and gauges for temperature and pressure.

Method

1. Cover the base with water.
2. Add material for autoclaving ensuring screw caps are loosened.
3. Fix the lid by using the nuts and bolts (ensure balanced).
4. Ensure the pressure valve is loose.
5. Switch on the machine and allow to heat till about 100 ºC. At this point step will be emitted from the pressure valve.
6. Close the pressure valve and start the timing (normally 15 minutes)
7. Upon completion, switch off the machine and allow cooling below 80 ºC before loosening the pressure valve.
8. At about 60 ºC open gently allowing all steam to emerge while bolts are partly fixed before completely removing the lid.

**Appendix XX. DNA sequencing**

Sequencing of DNA is an important step and its general principle has already been outline (Section 4.12.19). The specific procedural steps involve obtaining a certain grade of DNA alongside primers and sending this material to a sequencing laboratory that if successful provides a file with readout of base pairs and the statistical accuracy of the reading. In most cases a reading was made in each direction (e.g. by providing the forward and reverse primer) allowing a consensus sequence to be produced.

Material

100 nm DNA Template (plasmid or PCR)..... 10 µl (210/280 higher than 1.5/1.5)
1 µM Primer Forward ..... 10 µl
1 µM Primer Reverse..... 10 µl
Sequencing form ..... 1
Purchase form ..... 1
(Average cost during the research was £4.50 per reactions, for two reactions or two primers (forward and reverse) £9)

Method

1. Preform a Nanodrop on the DNA template to confirm purity and weight per volume.

2. Prepare DNA dilution (if too low, vacuum drying the sample may increase concentration).
3. Prepare Primer dilutions.
4. Fill in sequencing form ensuring that the expected product has the right annealing temperature ($T_m$). Make sure any optimisations are correct using the annealing temperature used have already produced a PCR product. Provided the length of the product.
5. Add all material into a single bag with a purchase form and deliver to institution.
6. An email is normally returned the following day with sequence result.

**Appendix XXI. Serial dilution and minimal resistance**

A method for measuring how cells react to a compound can be done using a serial dilution. This was used to quantify the minimal resistance to hydrogen peroxide in *E.coli*. The method can be performed in either liquid media or on solid agar; however, solid agar provides a clear visual feedback by forming clear rings around disks containing a specific compound. The rings are indication of the compound having a detrimental impact on the cells, thus the larger the rings the greater the effect.

Material

Compound (e.g. 30 % $H_2O_2$) ..... 1 ml
$_{dd}H_2O$ (HPLC water) ..... 2 ml
LB-agar plate ..... 1
Stock culture ..... 1 ml
Swab ..... 1
Tweezers ..... 1
Sterile disks ..... 10 (paper disks from a hole puncher)

Method
1. Prepare 100 µl solution of the maximum concentration applied (e.g. 1/100) of the stock concentration.
2. To prepare a 1:100 serial dilution, remove 1 µl of working concentration, add to an empty microcentrifuge tube and add 99 µl. Repeat procedure three times for a total of five dilutions (1/100, 1/1000, 1/10000, 1/100000, 1/1000000)
3. Place one disk in each of the five dilutions
4. Using a sterile swap moist in stock culture and spread over a fresh LB agar plate containing appropriate antibiotics to form a bacteria lawn.
5. Using flame sterilised tweezers, remove disks, gently dry and place around the circumference of plate in a clock-like manner
6. Ensure that the plate is labelled appropriately and with disks

7. Place in incubator overnight
8. Repeat until with smaller or higher concentration until desired bands are produced

## Appendix XXII. Fermentation

A major problem that may occur during this type of set-up is contamination, however, due to rapid division rate in *E. coli* (i.e. doubling every 20 minute in optimum conditions) it was unlikely that other organism would be able to outcompete these.

After autoclaving, the fermenter was inoculated with 10% volume to volume of culture (i.e. 200 ml) and antibiotics (5 ml ampicillin of 50 μg/ml stock) were injected into the feed through silicon tubes. The basic set-up used 2 pumps, one to pump fresh broth from the feed into the fermenter, and a second to extract surplus culture from the fermentation surface. Monitoring and diluting the culture at a controlled rate could keep growth rate at a constant. The growth rate must be measured at intervals by checking the optical density (O.D.) using a spectrometer and the pumping speed regulated accordingly until the desired equilibrium is found.

Materials for setting up chemostat

FerMac 250 oxygen ..... 1
FerMac 260 pH controller..... 1
FerMac 230 temperature and agitation..... 1
Spage..... 1
Temperature probe..... 1
Air-pump (Air-con) ..... 1
Peristaltic-pump (Watson Marlow 520 or similar)... 1
Peristaltic-pump (Watson Marlow 101 UR) ..... 1
Fermentation unit (2 L) ..... 1
Conical flasks (5 L)..... 1
Universal tube ..... 1
Tubing (20 mm) ..... 5 m
Tubing (10 mm) ..... 5 m
Connectors (10 mm) ..... 3
Air filters (0.22 μm) ..... 7
Cable ties..... 10
Metal table..... 1
Laboratory stands ..... 3
Clamps and connectors..... 7

## Appendix XXIII. Ethics application and approval

In order for this research to be carried out to its full extent both in terms of laboratory work and exhibiting outcomes an ethics approval was required. The reason for this need was two-folded

(1) to provide an official 'awareness' that it was carried out according to official protocols, and (2) to ensure that the University would not be thrown into disrepute as issues around GMOs have been a sensitive issue in particular the manner it has been disseminated in the public. The documentation for the approval was extensive and is beyond what can be included in this thesis; however, it has been added to the accompanied DVD. It is extensive precisely because it required details of all chemicals and organisms used in the research by means of COSHH forms. The following provides was the resulting committee approval (an official letterhead was included in the original document).

**PRIVATE AND CONFIDENTIAL**
**Howard Boland**
**School of Media, Arts and Design**
**University of Westminster**
**115 New Cavendish Street**
**London, W1W 6UW**

13 March 2012

Dear Howard

**Ethics App. No. 11_12_18**
**Howard Boland: School of Media, Arts and Design**
**Mode: MPhil/PhD**
**Supervisor: Mark Clements (School of Life Sciences)**

**Proposal title: Art from Synthetic Biology**

I am writing to inform you that your application (Part A and Part B) was considered by the Committee (by correspondence) on 11 and 12 March 2012. The proposal was **approved**.

The Committee would like to inform you that your COSSH forms as attached to this application (supplementary information), were exemplary, and that this is an example of good practice.

Also given the answers provided in Form Part A, there research appears to have no or minimal ethical implications (in line with the Code of Practice Governing the Ethical Conduct of Research), and therefore a full application (including Part B) was not required. The Committee noted that external funding may have been the reason for gaining institutional ethical consideration/approval.

If your protocol changes significantly in the meantime, please contact me immediately, in case of further ethical requirements.

Yours sincerely

Huzma Kelly
Secretary, Research Ethics sub Committee
cc.

Dr. John Colwell (Chair, Research Ethics Sub Committee [RESC])
Dr. Mark Clements (Supervisor)
Prof. Taj Keshavarz (School Ethics Advisor)
Dr. Peter Goodwin (School Ethics Advisor)
Mike Fisher (Research Degrees Manager)
Dr. Helen Rowley (RESC Member)
Dr. Keith Redway (RESC Member)

I am advised by the Committee to remind you of the following points:

1. Your responsibility to notify the Research Ethics sub Committee immediately of any information received by you, or of which you become aware, which would cast doubt upon, or alter, any information contained in the original application, or a later amendment, submitted to the Research Ethics sub Committee and/or which would raise questions about the safety and/or continued conduct of the research.

2. The need to comply with the Data Protection Act 1998

3. The need to comply, throughout the conduct of the study, with good research practice standards

4. The need to refer proposed amendments to the protocol to the Research Ethics sub Committee for further review and to obtain Research Ethics sub Committee approval thereto prior to implementation (except only in cases of emergency when the welfare of the subject is paramount).

5. You are authorised to present this University of Westminster Ethics Committee letter of approval to outside bodies, e.g. NHS Research Ethics Committees, in support of any application for further research clearance.

6. The requirement to furnish the Research Ethics sub Committee with details of the conclusion and outcome of the project, and to inform the Research Ethics sub Committee should the research be discontinued. The Committee would prefer a concise summary of the conclusion and outcome of the project, which would fit no more than one side of A4 paper, please.

7. The desirability of including full details of the consent form in an appendix to your research, and of addressing specifically ethical issues in your methodological discussion.

## Appendix XXIV. HSE application and approval

The research involved exhibiting GMOs in the public domain and an official approval for venues was obtained by liaising with the HSE to extend the University's GMO licencing to external premises.

### Appendix XXIV.I. Answers to HSE questions

Prior to gaining HSE approval for extending the University's GMO licencing an email with the following questions were answered (Email correspondance, Boland, 2012a; Sankey, 2012).

**Aim / Objective**

The purpose of this activity is to exhibit outcomes developed through my doctoral research 'Art from Synthetic Biology' that developed several artistic works involving synthetic biology and microbiology.

These works offer a novel and exciting way for audiences engage both artistic and scientific aspects of material and processes often inaccessible. The output of this study can help raise the University's profile by providing a fresh approach in terms of engagement with the public. Very little work exists in the area of art and there is a need in the sciences to find ways of communicate often-complex knowledge processes. Whilst approaches that use other visual media such as computer art, film and photography are helpful they do not convey the actuality of such material and this study brings into view such material understandings. As it stands only few galleries have exhibited works of this nature worldwide and it would be the first of its kind in the UK. The project is therefore seen as an important drive to begin to tackle issues around synthetic biology, art and society, and has been acknowledged through funding of this project by the Arts and Humanities Research Council as part of the doctorial research competition.

As such the objective is to provide a platform that allow these works to be exhibited. The nature of these works use laboratory strain *E. coli* (e.g. XL1-Blue, DH5-alpha and YYC-912) and natural bacteria such as sewage-based consortiums (mainly *Clostridium*). Modifications have been made by constructing and introducing plasmids based on the Library of Standardised Parts (MIT) to create biosensors. For example, it uses a promoter extracted from *E. coli* genome involved in oxidative stress with a fluorescent reporter construct or production of enzymes that can convert isoamyl alcohol into isoamyl acetate (banana oil).

**Addresses at which the exhibitions will take place...& are there likely to be more in the future?**

Kings Place, 90 York Way, London, N1 9AG, 020 7520 1490

University of Westminster, 309 Regent Street, London, W1B 2UW, 020 7911 5000

ICA, The Mall London SW1Y 5AH 020 7930 3647

Wellcome Trust, Gibbs Building 215 Euston Road, London NW1 2BE 020 7611 8888
Old Operating Theatre, 9a Saint Thomas Street London SE1 9RY 020 7188 2679

P3 Ambika, University of Westminster, 35 Marylebone Rd, London NW1 5LS

Grants Museum of Zoology, 21 University Street London, Greater London WC1E 6DE, 020 3108 2052

**What the installation will entail including volumes, flasks, petri dishes, fermenters etc;**

*Stress-o-stat*:
Fermentation unit setup as a chemostat with two 5 litres deposit/reservoir flasks, a fermenter (2 liter volume) and Graham condenser (500ml). Max. culture volume 6 litres.

*katE:*
10 cm diameter Petridish (max. 3)

*Banana Bacteria.*
Florence flasks (2 x 250ml). Max. culture volume 400ml.

*Transient Image*:
Mounted display of HPLC-tubes or equivalent (max. 100 x 2ml tubes).
Max. culture volume 200ml.

*Bacteria Compass*:
Slides, Microscope and magnet. Max. culture volume 10ml.

**What containment measures will be used?**

During exhibition an official person (i.e. artist or staff) will supervise the exhibit to ensure the material is secured and ensure a perimeter between audience and display. The level of 'interaction' should prevent touching the displays. The material is enclosed in either glassware or petri dishes and securely mounted.

**Measures to protect the environment**

Exhibits happen within building spaces and are therefore not in direct contact with an outside environment. The most important element in protecting the environment will be control of transport and spillage arrangements.

Full biological COSHH and GMO risk assessments have been carried out for the proposed work. This assessment has classified the work as posing minimal potential risk. Prior to exhibitions a full risk assessment will be carried out at the exhibition venue and appropriate actions taken to minimise risks (i.e. avoid accidental spillage and contact of the biological material with the public).

Some of the biological material to be exhibited will be unmodified micro-organisms (non-pathogenic environmental isolates) and hence class 1 imposing minimal risk to both health and environment. Materials that include genetic modifications will be incorporated in standard laboratory bacterial strains (*E. coli*) that have been deliberately manipulated to cause minimal harm and are weakened so to minimise the risk of growth outside laboratory conditions.

**Transport, spillage & waste disposal arrangements.**

Transportation from laboratory space to gallery space is such that most material is prepared in the laboratory. The material will be covered in thick sealed plastic biohazard bags to prevent any spillage or release into the environment throughout the journey. Ethanol, bleach and appropriate absorbent disposable cloths will be used to mop up and sterilise any accidental spillages that occur within the area used for the exhibition. The car and each material will be equipped with a

biohazard sticker. To minimise the risk, shortest routes from the laboratory to exhibition space has been considered and any spillage during transport will be clean up using bleach. Biohazard autoclave bags and plastic gloves will be used to dispose of any contaminated materials which will be easily accessible throughout the duration of the exhibition and returned to the University of Westminster for autoclaving and disposal using standard containment procedures.

**What organisms & what modifications (deletions / insertions / stability etc)?**

A GM risk assessment approved by the Universities Ethics committee can be provided.

The plasmids used are non-mobilised derived pUC and the strain types disabled K-12 *E. coli*.

SB1A3 (plasmid): is a high copy number plasmid carrying ampicillin resistance. The replication origin is a pUC19-derived pMB1 (copy number of 100-300 per cell).

XL-1 Blue (*E. coli*): endA1 gyrA96(nalR) thi-1 recA1 relA1 lac glnV44 F'[ ::Tn10 proAB+ lacIq Δ(lacZ)M15] hsdR17(rK- mK+)

- nalidixic acid resistant
- tetracycline resistant (carried on the F plasmid)

DH5-α (*E. coli*): F- endA1 glnV44 thi-1 recA1 relA1 gyrA96 deoR nupG Φ80dlacZΔM15 Δ(lacZYA-argF)U169, hsdR17(rK- mK+), λ–

- nalidixic acid resistant
- An Hoffman-Berling 1100 strain derivative (Meselson68)
- Promega also lists phoA

YYC-912 (*E. coli*): F-, Δ(argF-lac)169, λ-, poxB15::lacZ::CmR, IN(rrnD-rrnE)1, rph-1, tnaA5

*Stress-o-stat*:
Strain: XL-1 Blue, Plasmid: pSB1A3, Media: LB-broth
plasmid insert: promoter *katE* (Catalase HPI) + BBa_E0840 (GFP reporting construct)

*katE:*
Strain: DH5-α, Plasmid: pSB1A3, Media: LB-agar
1. Plasmid insert: promoter *katE* (Catalase HPI) + BBa_E0840 (GFP reporting construct)
2. Plasmid insert: promoter *katE* (Catalase HPI) + BBa_J06702 (GFP reporting construct)

*Banana Bacteria:*
Strain: YYC-912, Plasmid: pSB1A3, Media: M9
Plasmid insert: BBa_ J45250

*Transient Image*:
Consortium of Sewage bacteria (mainly Clostridium), Media: Minimal (MSB)

**Your assessment of risk of infection / who could be exposed?**

The risk of infection is considered low and it is unlikely that audience would become unwell if accidentally exposed to the material unless severely immunocompromised (a warning sign can be put up advising immunocompromised individuals from approaching the display). In the unlikely event of eye exposure, an eye rinse device will be available and if unwell medical attention will be sought. Ingestion is unlikely, but in case, medical attention will be sought. Contact details of the nearest Accident and Emergency Department will be at hand during the exhibit.

The material is of low-risk to participants but to minimise any potential risks I will implement a rigorous health and safety procedures (identified through risk assessments of planned public exhibitions) so that displays are designed with specific attention to secure and minimize any potential spillage and accidental exposure of the public to the microorganisms.

Appendix XXIV.II. Response from HSE

The following two correspondences were of importance since they provided the key emails stating the approval and methods of notification.

> *Howard - you e-mail is timely. Unfortunately this was not something that I was able to authorise myself. However, it had not been forgotten & I now have an answer for you. Since the GMOs used will be based upon standard laboratory bacterial strains of E. coli & since it will be enclosed in either glassware or petri dishes and securely mounted then we are happy for these activities to go ahead. However, since Sandra will be setting up temporary premises notifications for the listed venues then can I please request that you ensure that when the activities are complete that Sandra is informed so that they can be removed from our database. It will be sufficient to do this once when the series is complete.... although if the timeline is protracted then Sandra may require a regular update?*
>
> (Email correspondance 23-October, Sankey, 2012)

To ensure complete clarification in terms of official approval – an email was sent pressing if any additional documentation or letter of confirmation were needed. The following was HSE response.

> *No additional paperwork is required from you & we were not proposing to issue any further written confirmation other than my e-mail.*
>
> *The venues listed in your assessment document are:*
>
> - *Kings Place, 90 York Way, London, N1 9AG, 020 7520 1490*
> - *University of Westminster, 309 Regent Street, London, W1B 2UW, 020 7911 5000*
> - *ICA, The Mall London SW1Y 5AH 020 7930 3647*
> - *Wellcome Trust, Gibbs Building 215 Euston Road, London NW1 2BE 020 7611 8888*
> - *Old Operating Theatre, 9a Saint Thomas Street London SE1 9RY 020 7188 2679*

- *P3 Ambika, University of Westminster, 35 Marylebone Rd, London NW1 5LS*
- *Grants Museum of Zoology, 21 University Street London, Greater London WC1E 6DE, 020 3108 2052*

*These will be (temporarily) added to our database as locations under the University of Westminster. If you wish to exhibit at additional venues that are not on this list then please inform Sandra in advance so that the information we hold can be updated.*

*Of course, if you change the activity so as to change the risk, then you should inform us of that too.*

(Email correspondance 24-October, Sankey, 2012).

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# Exhibitions and Conferences

As a result of this research, I participated in the following outputs:

**Awards:**

Designers & Artists 4 Genomics Award (€25,000), Naturalis Biodiversity Centre, Leiden, Netherlands (2012 -2013)

Travel Grants, University of Westminster (2012) - Mutamorphosis 2012, Prague (Czech Republic)

Travel Grants, University of Westminster (2012) - Re-new 2012 Digital Art Festival, Copenhagen (Denmark)

Gold Award, iGEM UCL (2012)

Bronze Award, Westminster iGEM (2012)

Travel Grants, University of Westminster (2012) - The Two Cultures: Visual Art and the Sciences c.1800-2011, York (United Kingdom)

Travel Grants, University of Westminster (2012) - Techfest 2012, Mumbai (IN)

Platinum Award, iGEM UCL (2012)

SGM Summer Scholarship, Society for General Microbiology & School of Life Sciences (2011)

European Culture Grant, Commission Award (€99,000), as part of European Public Art Centre (2010-2012)

Doctoral Award, Arts and Humanities Research Council (2010 - 2012)

Doctoral Studentships, University of Westminster (2009-2010)

**Exhibitions:**

Upcoming: DA4GA, Naturalis Museum, Leiden, Netherlands
Artwork: *Living Mirror* (2013)

Art from Synthetic Biology, Royal Institute of Great Britain
Artworks: *Stress-o-stat* (2011), *Transient Images* (2011), *Banana Bacteria* (2011), *katE (2011), katE Red* (2012), *Bacteria World* (2012), *Bacteria Light Sensor* (2012), Bacteria Compass (2012).

Evaporation of Things, Inspace, Edinburgh, Scotland
Artworks: *Transient Images* (2011), *Stress-o-stat* (2011)

Re-new 2012 Digital Art Festival, Aalborg University, Copenhagen, Denmark
Artwork: *Stress-o-stat* (2011)

Cage Rattling #1: Kill Switch, Kings Place, London, UK
Artwork: *Stress-o-stat* (2011)

Graduate School Launch, University of Westminster, London, UK
Artworks: *Stress-o-stat* (2011), *Transient Images* (2011), *Banana Bacteria* (2011)

Techfest 2012, IIT Bombay, India
Artworks: *Stress-o-stat* (2011), *Banana Bacteria* (2011)

**Conference Presentations:**

Mutamorphosis 2012, New Stage of the National Theatre, Prague, Czech Republic

Synthetic Biology Society Kick-off, UCL, London, UK

International Media Arts Conference IMAC 2012, Aalborg University, Copenhagen, Denmark

Cage Rattling #1: Kill Switch, Kings Place, London, UK

Synthetic Biology Speed Debate, UCL, London, UK

The Thirteenth International Conference on the Synthesis and Simulation of Living Systems "Evolution in Action", Michigan State University East Lansing, Michigan, USA (Declined)

Subtle Technologies, Ryerson University, Toronto, Canada

The Two Cultures: Visual Art and the Sciences c.1800-2011, University of York, UK

Synthetic Biology: Machine or Life?, Dana Centre, Science Museum, London, UK

**Curatorial:**

Risk or Right? - Worlds first Public BioBrick: Exploring Public Access to the Tools of Synthetic Biology, Grant Museum of Zoology, London, UK

European Public Art Centre: The Emigration (Martynas Gaubas), Bishop's Square, Spitalfields, London, UK

European Public Art Centre: Dreaming of a Butterfly, Antonio Caramelo, Bishop's Square, Spitalfields, London, UK

Synthetic Biology: Machine or Life?, Dana Centre, Science Museum, London, UK

European Public Art Centre: Bee Box, Anne Brodie, Bishop's Square, Spitalfields, London, UK

**Interview:**

#A.I.L - artists in laboratories, episode 3 with Régine Debatty (We Make Money Not Art), Resonance 104.4 FM, 2012

**Advisory/Supervisory Roles:**

Postgraduate Thesis Supervisor/Specialist Tutor (2012-2013), The Bartlett, University College London (UCL), UK

Initiator & Advisor, *iSTEM* (Synbio & Cancer Stem Cells), Westminster iGEM 2012, University of Westminster, UK

Advisor, *Plastic Republic* (Synbio binding microplastics in ocean), UCL iGEM 2012, University College London (UCL)

Practical Supervisor Synthetic Biology, MSc Medical Genetics Students 2012, University of Westminster, UK

Panel Judge, Genetic Circuit Challenge 2011 – 2012, Synthetic Biology Society, University College London (UCL), UK

Advisor, Synthetic Biology Society (2011 - 2012) University College London (UCL), UK

Nutritec, Biotechnology YES 2011, Institute for Enterprise and Innovation, Nottingham University Business School & Biotechnology and Biological Sciences Research Council (BBSRC), UK

Advisor, *E.coili* (Synbio - Supercoiling DNA), UCL iGEM 2011, University College London (UCL), UK

Synthetic Biology Supervisor, SGM Summer Scholarship 2011, funded by the Society for General Microbiology and the School of Life Sciences at University of Westminster, UK

Workshop Organiser, Bio art Forum 2010 The Centre for Research and Education in Arts and Media (CREAM) and The Communication and Media Research Institute (CAMRI), University of Westminster, London, UK

# Glossary of terms

Given that the thesis contains several technical terms, the following glossary is provided:

**A3 assembly:** (three antibiotic assembly) method for assembling two BioBricks™ parts together. It reduces the number of steps needed in assembly processes (by skipping gel steps) and is useful when working with small parts (i.e. short sequences that may be invisible on gels). It differs from common two-way assembly in that the hosting backbone contains a different antibiotic-cassette than the donor parts.

**Abstraction:** term borrowed from software that simplifies components by hiding, or 'black boxing' information, facilitating their use and re-use. Applied to biological parts it suggests being able to use a composite part without needing to know details about its subcomponents.

**Agar:** (or nutrient agar) generic term for any culture medium that uses agar as the gelling agent. In most cases, this research uses Luria agar, a standard growth media for plate cultivating of *E. coli*.

**Agar plate:** a petri dish containing agar based growth medium (see agar).

**Agarose:** a highly purified agar derivative used as a gelling agent (see Agarose gel).

**Agarose gel:** gel resulting from the polymerisation of agarose by heating agarose suspended in buffer solution followed by casting (into a rectangular shape and using a comb for wells) and cooling. The gel is used in electrophoresis to separate and visualise DNA fragments.

**Algorithms:** set of rules, instructions, calculations or other problem-solving operations commonly used in computer programs.

**Aliquot:** volume of a total amount of solution.

**Amino acids:** basic building block of a protein. In DNA there are four amino acids and these can (naturally) encode for proteins by utilising a total of 20 amino acids.

**Amplification:** term used to describe processes of generating more genetic material using a PCR (see polymerase chain reaction or PCR).

**Anaerobic:** (without oxygen) term used to describe organisms requiring low or oxygen free conditions.

**Annealing:** condition where separated DNA strands become double stranded.

**Annealing temperature:** refers to a temperature condition where DNA anneals, this normally happens at 5ºC below the melting temperature DNA (where the duplex separate).

**Antibiotic:** chemical used to kill susceptible bacteria. It is used as a selection mechanism in genetics by allowing only bacteria with specific resistance (e.g. containing appropriate antibiotic cassette) to survive. It is used to conserve a specific set of genetic material.

**Antibiotic cassettes:** genes (with promoters) commonly found in plasmids to infer resistance to specific antibiotics.

**Antiseptic techniques:** (or sterile techniques) involves methods for reducing the risk of contaminants (e.g. unwanted fungi or bacteria) entering media or isolated growth environments. These include use of alcohol, flames and air filters.

**Assembly:** refers to a method of slicing and splicing DNA to build more complex genetic material.

**Autoclave:** sterilisation technique that combines temperature and pressure to destroy potential contaminants.

**Backbone:** refers to a plasmid that hosts a specific genetic part.

**Bacteria:** large group of single-celled, prokaryote microorganisms. Typically a few micrometres in length, bacteria have a wide range of shapes, ranging from spheres to rods and spirals.

**Base-pairing:** attachment of one polynucleotide to another, or one part of a polynucleotide to another part of the same polynucleotide, by base pairs.

**Basepairs:** refers to complementary nucleotides joined by hydrogen bonds; basepairing occurs between A and T and between G and C. Basepairs is used to describe the size of DNA such as a plasmid.

**Bases:** refer to four types of simple molecules or nucleotides (adenine, cytosine, thymine and guanine) that are the subunits (building blocks) of DNA and RNA.

**Behaviour:** a specific function performed by an organism.

**Bind:** in the context of laboratory work this normally refers to how DNA attaches to another piece of material allowing it to be isolated.

**Bio art:** as used in this research can be seen as an art form involving the transformation of intangible bio-scientific processes into concrete sensorial experiences in the actual living presence of bio matter.

**Bio design:** an emerging field of design, that much like bio art seeks to explore bio matter through creative processes. Bio design has so far mostly been speculative.

**Bio matter:** biological material from living, or recently living organisms.

**Bio media:** referring mostly to bio matter as employed by genetics, and how informatics enhance biological materiality. Bio media and bio matter is sometimes used interchangeably.

**BioBrick Foundation:** The BioBricks Foundation (BBF) is a public-benefit organisation founded in 2006 by scientists and engineers who recognised that synthetic biology had the potential to produce big impacts on people and the planet and who wanted to ensure that this emerging field would serve the public interest. Currently, the BioBricks Foundation is charting a technical standards framework that will serve as the driver and promoter of a high-quality, technical-standards process for synthetic biology based on BioBrick™ parts.

**BioBricks** (BioBrick™): standard for interchangeable parts, developed with a view to building biological systems in living cells.

**Biodegradation:** mechanism involving the natural breakdown of compounds through the action of biological agents.

**Bioethics:** study of controversial ethics brought about by advances in biology and medicine.

**Bioinformatics:** use of computational methods to study biological data.

**Biological information:** information contained in the genome of an organism that directs its development and maintenance.

**Bioremediation:** involves the use of microbes to break down toxic or unwanted substances.

**Biosafety level:** precautions and containment rules for safely working with biological agents in laboratory facilities.

**Biotechnology** is the use of living organisms, often, but not always microbes, in industrial processes.

**Bp (basepairs):** (See basepairs).

**Bricolage:** refers to a process of putting something together by material available.

**Broth:** liquid medium containing a variety of nutrients used to grow cultures of bacteria and other microorganisms. (Broth and broth culture is sometimes used interchangeably).

**Broth growth:** a culture grown in liquid media.

**Buffer:** solution or agent normally used to support a reaction by increasing stability.

**C-LAB:** an arts collective and a small organisation that engages with critical and contemporary amalgamations of art and science. Headed up by London-based artists, Howard Boland and Laura Cinti, it focuses

on artistic explorations of meaning and idiosyncrasies involving life both organic and synthetic.

**Cell culture:** material entity consisting of a population of cells that is maintained *in vitro*.

**Cell membranes:** the semi-permeable membrane surrounding the cytoplasm of a cell.

**Cell pellets:** aggregation of cells produced by centrifugal force to a liquid containing cells in suspension.

**Cell:** the smallest structural and functional unit of an organism, which is typically microscopic and consists of cytoplasm and a nucleus enclosed in a membrane.

**Centrifuge:** apparatus for applying force to objects by rotating these around a fixed axis. The centrifugal force causes denser substances to separate to the bottom of the tube while lighter objects will tend to move to the top.

**Characterised:** a genetic part or composite that is well described.

**Chemotaxis:** the movement of a motile cell or organism, or part of one, in a direction corresponding to a gradient of increasing or decreasing concentration of a particular substance. Movement by a cell or organism in reaction to a chemical stimulus.

**Chlorophyll:** a green photosynthetic pigment usually found in organelles called chloroplasts and used by plants to harvest energy.

**Chromosome:** DNA structures containing part of the nuclear genome in eukaryote and sometimes referred to as molecules containing the prokaryotic genome.

**Clone:** a set of identical molecules of DNA.

**Cloning:** recombinant DNA molecules involving the insertion of a plasmid into a host cell without killing it.

**Collaboration:** the action of working with someone to produce something.

**Colony:** a visible cluster or assemblage of microorganisms growing on a agar culture medium that usually multiply to have the same genetic material.

**Commercial kits:** a set of components used to perform a specific task such as extracting plasmid DNA.

**Compatible ends:** sequence ends or overhangs left behind when restriction enzymes cleave DNA.

**Competent:** a culture of bacteria that have been treated, for example, by soaking in calcium chloride, so that their ability to take up DNA molecules is enhanced.

**Competent cells:** (See Competent).

**Complementary DNA (cDNA):** a double-stranded DNA copy of an mRNA molecule.

**Consequentialism:** a theory in normative ethics concerned with whether an act is morally right depends on its consequences of the act.

**Cryopreserved:** a method for long-term preservation at low-temperature (e.g. -80ºC). For instance, this can be done with bacteria by adding glycerol.

**Cultured broth:** (See broth culture).

**Cut:** term referring to digesting or splicing of genetic material using restriction enzymes (see digestion).

**Databases:** a structured set of data held in a computer commonly accessible in various ways.

**Denature:** a loss of chemical function, usually due to some heat or chemically induced structural change. For example, heating a protein causes it to lose its three dimensional form and it no longer functions correctly. This is useful in processes such as PCR.

**Deontological:** a theory in normative ethics concerned with the duty, that is, normative theories of what is forbidden, required or permitted.

**Devices:** a device a genetic construct produced by combining one or more standard biological parts (usually to perform a more complex operation).

**Differentiation:** a cellular processes of adoption by acquiring specialised biochemical or physiological role.

**Digestion:** a process of cutting DNA. Digestion is done by restriction enzymes.

**DNA:** Deoxyribonucleic acid, a self-replicating molecule present in nearly all-living organisms. It is the carrier of genetic information. Examples of DNA material are plasmids and the genome.

**DNA cloning:** (see cloning)

**DNA ligase:** an enzyme capable of repairing DNA and therefore used to join genetic material.

**DNA sequencing:** the technique for determining the order of nucleotides in a DNA molecule and normally results in information sequence readout.

**DNA synthesis:** chemical assembly of nucleotides in a specified order normally done by a commercial company.

**DNA template:** the target region of the DNA to be amplified (see also amplification).

**Downstream:** a term used to describe the direction of a DNA sequence that is towards the 3' end of a polynucleotide.

**EcoRI:** a restriction enzyme used in BioBrick™ assembly.

**Electrophoresis:** (or Gel electrophoresis) a process of separating DNA fragments by size.

**Electroshock:** a method for enabling cells to take up exogenic DNA.

**Elute:** process of releasing or extracting a material from another. For example, extracting DNA from a filter.

**Enzymatic:** a reaction whereby components are converted by enzymes.

**Enzymatic assembly processes:** using restriction enzymes in genetic assembly (see assembly).

**Enzyme:** a substance produced by a living organism that acts as a catalyst to bring about a specific biochemical reaction.

**Escherichia coli (*E.coli*):** a gram-negative bacterium widely used in microbiological and genetic research as well as in protein production.

**Ester:** an organic compound commonly found in fragrances and essential oils.

**Ethidium bromide:** an intercalating agent commonly used as a fluorescent tag (nucleic acid stain) in molecular biology laboratories for techniques such as agarose gel electrophoresis.

**Evidence-based:** a process involving data gathering through iteration, documentation and material evaluation in order to make decisions about construction. This was particularly when working with material of an invisible nature since evaluation is often done indirectly rather than through direct observation.

**Fermentation:** a method commonly used in growing large volumes of bacteria, it uses specific set-ups to control growth conditions.

**FinchTV:** DNA sequence analysis software program.

**Flanked:** refers to beginning or end area of a linear sequence or a genetic part.

**Fluorescent agent:** (See Ethidium bromide).

**Fragments:** various sizes of linearised portions of DNA.

**Gel:** (See agarose gel).

**Gel analysis:** (See electrophoresis).

**Gel bands:** visible band that represent the size and quantity of DNA fragments on a gel.

**Gel Purification:** a method for purifying DNA fragments from agarose gels.

**Gene:** a part of the DNA molecule of a chromosome that encodes for a protein.

**Gene expression:** the process by which the information in the DNA sequence of a gene is transcribed into messenger RNA and translated into a protein.

**Genetic code:** the rules that determine how triplet of nucleotides becomes encoded into other amino acids during protein synthesis.

**Genetic engineering:** a change in an organism's genetic make-up made possible using recombinant DNA technology. Normally this involves either adding exogenic material or making changes to the genome.

**Genetically modified material:** an organism or cell that is the output of a genetic transformation process.

**Genome:** complete genetic sequence for an organism.

**Gibson assembly:** a fast assembly method to generate multi-part systems using enzymes and sequence linkers in a single PCR.

**Glass beads:** small sterile glass beads used to distribute bacteria on plates.

**Glycerol:** a viscous solvent used as an anti-freeze agent to disrupt crystal formation.

**Glycerol stock:** a stock solution consisting of glycerol and water. Mixed with culture broth it allows long-term storage of bacteria in -80ºC freezer.

**Golden Gate:** is a one-step DNA assembly protocol that can join at least nine distinct DNA fragments into one plasmid vector (see also Gibson Assembly).

**Gram staining:** a differential stain that divides bacteria into two groups, gram-positive and gram-negative based on the ability to retain crystal violet when decolorized with an organic solvent such as ethanol.

**Green fluorescent protein (GFP):** a protein that is used to label other proteins and whose gene is used as a reporter gene.

**Growth:** the increase in number and spread of small or microscopic organisms.

**Hard agar:** nutrient agar containing a higher percentage agar producing a harder surface.

**Hardware:** the machines, wiring, and other physical components of a computer or other electronic systems.

**Heat-shock:** a short and rapid increase in temperature used in genetic transformation to enable plasmids to enter the membrane. Cells are prepared specifically to allow heat-shock and recovery (see competent cells).

**Idempotent assembly:** a process of assembly that employs a specific standard (e.g. RFC-10) where two parts adhering to the standard can come together to form a new part retaining this standard.

**iGEM:** the international Genetically Engineered Machine competition, an annual University competition spun out of Massachusetts Institute of Technology, and organised by the iGEM Foundation.

**Immersive:** a process of entering into an environment and experiencing it as a totality.

**In silicon:** a biological processes or model simulated on a computer.

**Incubator:** an apparatus for growing microorganisms under controlled conditions.

**Inducer:** a substance (normally chemical) that induces expression of a gene.

**Intercalates:** the insertion of additional material between the parts. For instance, Ethidium bromide becomes inserted into the DNA duplex allowing it to be visualised (see Ethidium Bromide).

**Intergenic region:** a region between adjacent genes.

**Inverter:** takes an input signal and produces the opposite output signal.

**Iteration:** a repetition of a processes or a series of steps employing same or small variation to the type of material and procedure used.

**Laboratory:** a facility that provides controlled conditions for performing experimentation and measurements.

**Library of standardised parts:** (or partsregistry.org) is an online database to browse genetic parts and a central repository of physical parts.

**Ligase:** an enzyme that repairs DNA and is used in recombination processes.

**Ligating:** a process of binding together compatible DNA strands. Ligation requires an enzyme (see ligase) that repairs DNA ends.

**Linear product:** a plasmid that has been cut or digested with a single enzyme (at a unique enzymatic site) causing the plasmid to reconfigure its structure from circular to linear. This is used in electrophoresis to determine the size of a plasmid.

**Low-copy number:** refers to plasmids able to replicate only a few times within a cell (5-10 copies per cell). Low-copy number therefore produces less exogenic material in each cell.

**Lysing:** the physical rupturing of a cell (either partial or complete).

**Lysis:** the disintegration of a cell by rupture of the cell wall or membrane.

**Lysogenic broth:** a common growth media used to cultivate *E. coli*.

**Material transfer agreements (MTA):** a legal agreement between institutions or groups during transfer of material from one institution to another that reserves certain rights to the material holder.

**Measurement:** the quantitative assessment of a biological function. Measurements can be made of a part, device or system.

**Media:** a term commonly used in biology to mean a solution or solid allowing organisms to grow. In digital terms it refers to an entity that store a specific set of information.

**Micro-organism (microbe):** a small living thing. The group includes bacteria, archaea, protozoa, algae, fungi and viruses.

**Mini-prep:** a method used to extract DNA from a culture (e.g. overnight growth).

**Minimal genome:** an attempt to minimise (genetic) components needed to sustain life.

**Minimal media:** a stringent and often specific growth medium or culture medium is a liquid or gel designed to support the growth of microorganisms.

**Molecular biology:** a branch of biology that deals with the structure and function of the macromolecules (e.g., proteins and nucleic acids) essential to life.

**Mould:** refers to a cavity allowing an appropriate material to be casted into its form.

**Mutagenesis:** a process that changes a single or a series of basepairs in order to disrupt or change the sequence or its function.

**Mycelium:** a branched network of fungal hyphae.

**NanoDrop:** a cuvette free spectrophotometer to take a small amount of material (e.g. DNA) and provides qualitative and quantitative information.

**Nanoparticles:** a small particle behaving like individual objects. Diameters of these particles vary from (10,000-1 nanometre).

**Nanotechnology:** refers to the manipulation of matter (normally inert) on atomic and molecular scales.

**NEBcutter II:** a web application to analyse restriction sites of a sequence.

**NotI:** a restriction enzyme present in BioBrick™ standards but not commonly used.

**Open Reading Frame:** a region of a DNA sequence from the start-codon to the stop-codon. It is commonly thought that genes can be found within this area. Notably, since a codon is a triplet of basepairs there are six different ways of reading (called a reading frame).

**Origin of replication:** a sequence required in all plasmids for replication. There are

different types of origins of replication that impact the copy-number per cell.

**Orthogonal ribosome:** a synthetic ribosome coexisting with the natural ribosome and used to produce alternative types of proteins. Orthogonal ribosome can receive quadruplets instead of triplet codons and thereby expand the types of proteins produced.

**Overhangs:** a single stranded tail left after a DNA sequence is cleaved by a restriction enzyme.

**Oxidative stress:** Physiological stress caused by increase in reactive oxygen that may destabilise cellular processes.

**Part:** is a functional genetic sequence compatible with a specific assembly standard (e.g. RFC-10).

**PCR:** a technique for amplifying DNA of known or unknown sequence. The method provides a way for making multiple copies of a DNA sequence, involving repeated reactions with a polymerase.

**PCR product:** is double stranded fragment of DNA that is the specified output of a PCR.

**Phenotype:** an observable characteristic in an organism.

**Plant tissue culture:** the growth in an artificial medium of cells derived from living plant tissue.

**Plasmid Backbones:** (See backbone).

**Plasmids:** a genetic structure in a cell that can replicate independently of the chromosomes, typically a small circular DNA strand. Plasmids are commonly used in laboratories for genetic manipulation.

**Plating:** a method for inoculating bacteria on solid media.

**Plug n' Play:** a multi-part assembly method using linkers to join parts in a single PCR reaction (see also Gibson Assembly and Golden Gate).

**Polymer:** a compound made up of a long chain of identical or similar units.

**Polymerase:** an enzyme that synthesizes RNA on a DNA or RNA template.

**Polymerase chain reaction:** (See PCR).

**Post-biological:** a concept understood through multiple parameters but taken here to mean new material conditions emerging from modern biotechnologies such as tissue engineering, genetics and nanotechnology.

**Posthuman:** a condition emerged from humans increased involvement with and reliance on technology and how this impact and alters the relationship with our own body and the world.

**Precipitate:** a formation of solids inside a solution.

**Prefix:** an area at the beginning of a sequence (technically based on a direction 5'-3').

**Primer 3:** software (engine) used to design primers.

**Primers:** a short piece of DNA (or oligonucleotide) that attaches to a single-stranded DNA molecule and provide a start point for strand synthesis.

**Promoter:** sequence of DNA to which RNA polymerase binds for initiation of transcription.

**Propidium Iodide staining:** a staining method for observing dead and living cells.

**Protein:** a folded long chain molecule consisting of amino acids. Proteins are required for the structure, function, and regulation of an organism, cell/cells, tissues, and organs.

**PstI:** a restriction enzyme used in BioBrick™ assembly.

**Purification:** (See DNA purification).

**Quantification:** using a machine or gel to derive a numerical value.

**Readymade:** ordinary manufactured objects that the artist selected and modified. It involved a minimum amount of interaction between artist and the artwork.

**Receivers:** a set of genetic elements that responds to an extracellular input.

**Recombinant:** in genetics, describes DNA, proteins, cells or organisms that are made by combining genetic material from two different sources.

**Recombinant methods/Recombinant DNA technology:** the techniques used in carrying out genetic engineering; they involve the identification and isolation of a specific gene, the insertion of the gene into a plasmid, and the production of large quantities of the gene and its products.

**Red fluorescent proteins (RFP):** a protein re-emitting red light upon excitation from a different light source.

**Reporter genes:** a set of genetic elements that produces proteins with observable colours or light in response to a specific signal. In other words, reporter genes produce proteins to report a specific condition. Reporter genes are frequently used to quantify the level of expression.

**Reporters:** (See reporter genes).

**Restriction enzyme:** an enzyme that recognises and cleaves a specific DNA sequence.

**Restriction sites:** a site or a signature sequence the can be recognised by a restriction enzyme.

**RFC-10:** a standard for interchangeable parts based on idempotent assembly. BioBrick™ RFC[10] is currently the most commonly used assembly standard.

**Ribosome Binding Site (RBS):** the sequence of RNA to which ribosome binds for initiation of translation. In synthetic biology these are used as parts to improve translation ability.

**RNA:** a single stranded DNA sequence.

**Scars:** the remaining sequence between two parts when performing idempotent assembly. The scar results from two different but compatible restriction sites joining and in the process generating a sequence that can no longer be digested or cut.

**Selective antibiotics:** (See antibiotics).

**Selective media:** media containing selective antibiotics.

**Senders:** a set of genetic elements that produces an extracellular input.

**Sequences:** a sequence of basepairs or a sequence of DNA.

**Sequencing:** (See DNA sequencing).

**Shake-culturing:** a fast way of growing a broth culture by agitation or shaking to increase aeration.

**Shaker:** an apparatus capable of rapidly agitating a culture. Shakers are often combined incubators and shakers.

**Silencing:** switching off of a gene by any mechanism other than a change in the genetic sequence.

**Spectrometer:** an apparatus capable of measuring the light density. It is calibrated using a base-sample and then measured against a modified sample. For instance, this can say something about the turbidity or how dense a culture has become.

**SpeI:** a restriction enzyme used in BioBrick™ assembly.

**Standard:** a way of defining how parts are assembled (see RFC-10). It allows parts to be assembled together creating new, longer, and more complex parts, while still maintaining the format of the standard.

**Standardisation:** a series of assembly and characterisation rules. In time, these standards may allow the reliable physical and functional assembly of genetic parts into devices, and devices into systems.

**Standardised parts:** a part adhering to a specific standard such as RFC-10.

**Sterile techniques:** (See antiseptic techniques).

**Sterile tips:** refers to pipette tips that have been sterilised.

**Suffix:** an area at the end of a sequence (technically based on a direction 5'-3').

**Super optimal concentrate:** a sugar rich broth used to recover transformed cells.

**Swarming:** a rapid change in behaviour causing migration due to changing conditions.

**Swarming motility:** a rapid and coordinated translocation of a bacterial population across solid or semi-solid surfaces.

**Synthetic Biology:** a new area of biological research and technology that combines science and engineering. It encompasses a variety of different approaches, methodologies, and disciplines with a variety of definitions. The common goal is the design and construction of new biological functions and systems not found in nature.

**Technoscientific:** the role of science and technology in knowledge production through material networks.

**Terminator:** a sequence on the DNA causing the polymerase to stop transcription activity and release messenger RNA.

**Thematic representation:** (or simply 'representations') to refer to the range of artworks and expressions exploring the post-biological using non-biological media.

**Thermal cycling machine:** a machine programmable for rapidly changing temperature conditions (see PCR).

**Three-way ligation:** (See A3-assembly).

**Tissue culture:** involves methods for growing cells outside organisms. Tissue is normally understood here as cells capable of growing a connected structure.

**Tissue engineering:** a practice involving the production of biological material aimed at replacing or repairing tissue.

**Transcribe/Transcribing:** a process of copying or converting specific DNA sequences into RNA towards protein production. For example, DNA become transcribed to mRNA which in turn is translated into protein.

**Transcription:** (See transcribe).

**Transcription factors:** a protein that binds to the DNA to either enhance or reduce transcription.

**Transdisciplinary:** a research strategy that crosses many disciplinary boundaries to create a holistic approach.

**Transformation:** the introduction of extraneous DNA, especially by a plasmid.

This is normally done using heatshock or electroshock.

**Translation:** the process in which the sequence of a messenger RNA molecule is used to direct the order of assembly of amino acids to make a protein. This reaction is catalysed by ribosomes.

**Upstream:** a term used to describe the direction of a DNA sequence that is towards the 5' end of a polynucleotide.

**Utilitarianism:** a theory in normative ethics concerned with how the course of an action maximises benefits for those involved and minimises suffering.

**UV:** Ultra violet (see UV-light).

**UV documentation:** uses a UV-transilluminator and a camera to capture images of gels containing the flourescing agent Ethidium Bromide. With Ethidium Bromide bound to DNA it becomes visible during exposure to UV.

**UV-light:** (or ultraviolet radiation) refers to the use of high-energy light at the short-end of the light spectrum. UV-light is invisible to the human eye but the higher end of the light can be seen as a violet colour. UV-light is likely to cause damage to cells.

**UV-transilluminator:** a light-table or light arrangement using a UV-light source.

**Vectors:** (See plasmids).

**VF2:** a standardised primer (forward) that can amplify BioBrick™s.

**Virtual:** not physically existing as such but made by software to appear to do so.

**VR:** a standardised primer (reverse) that can amplify BioBrick™s.

**Waterbath:** a tank with water used to keep a stable temperature.

**XbaI:** a restriction enzyme used in BioBrick™ assembly.

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