BETTER

Navigating Imaginaries in Design and Synthetic Biology to Question "Better"

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Abstract

Designers, engineers, marketers, politicians, and scientists all craft motivating visions of better futures. In some of these, "better" will be delivered by science and technology; in others, the consumption of designed things will better us or the world. "Better" has become a contemporary version of progress, shed of some of its philosophical baggage. But better is not a universal good or a verified measure: it is imbued with politics and values. And better will not be delivered equally, if at all. "What is better?", "Whose better?", and "Who decides?" are questions with great implications for the way we live and hope to live.

At a time when social, economic, and environmental conditions place in question the dominant paradigms of better defined by globalisation and technology, *Better*, a PhD by project, investigates some of the powerful dreams triggered by a banal word and develops critical design techniques to find new ways to ask better questions. This thesis contends that the "dream of better" is so influential in advanced technological societies that it is what science and technology studies scholars term a sociotechnical imaginary. The imaginary is used as a critical design tool to examine better, revealing links between design and the emerging technoscience of synthetic biology and other ideological spaces, like Silicon Valley. As a young field, synthetic biology offers a space to test and expand critical design's potential.

The practical research includes six critical design projects that engage with synthetic biology and its vision-making processes, using techniques from designed fictions to curation. The written thesis comprises six chapters informed throughout by commentary on the practice.

The first chapter looks at the influence of dominant concepts of better on design, separating design's intrinsic optimism from engineering and market-led ideas of the optimum and optimisation. It situates critical design practice as an optimistic activity, seeking alternative meanings of better.

The next three chapters track how the imaginary of better has shaped synthetic biology and the field's evolving culture of design. Meanings of better have proliferated since 1999, as synthetic biology's visionaries promise to better biology, better the world, and even to better nature itself. But resistance has revealed the existence of alternative betters.

Chapter Five explores critical design's examination of synthetic biology's dreams of betters. Recognising the mutual colonisation of critical design and synthetic biology, which is contributing to the emerging platform of biodesign, the chapter discusses how navigating imaginaries can improve future critical practice. It encourages framing technoscience within society, rather than placing society downstream of it.

Chapter Six proposes that the social imaginary itself can be a critical design object. Designing "critical imaginaries" can open up our understanding of better, offering a process to reimagine the world. The critical imaginary is not a utopian effort to produce prescriptive visions of *how* the world ought to be. It is a heterotopian design technique to include diverse views and generate worlds that could be made, asking "*what* ought the world to be?"

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As Margaret Atwood reminds us in *The Handmaid’s Tale*: “Better never means better for everyone [...]. It always means worse, for some.” Thank you to my parents, Bruce and Karin, to my sister Georgia, and to Richard: you always make things good when faced with better.

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Author's Declaration

During the period of registered study in which this thesis was prepared the author has not been registered for any other academic award or qualification. The material included in this thesis has not been submitted wholly or in part for any academic award or qualification other than that for which it is now submitted.

Signature: 

Date: 28 February 2018

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The Problem of Better

I'm having one of those nightmares. I'm on stage, eyes burning from the lights, my feet glued to the plush red carpet, talking to a darkened room of the cleverest people in the world who can't make sense of what I'm saying. But this isn't a dream. I'm on stage at TEDGlobal 2011, delivering 18 minutes of "enlightenment". I'm sandwiched between Malcolm Gladwell, best-selling storyteller of the quirks and trends of our time, and Neil MacGregor, then director of the British Museum, who can recount the history of the world in one hundred objects. TED, which stands for Technology, Entertainment, and Design, is an organisation that distils great ideas into "infotainment". A TED conference is a high-profile gathering of powerful techno-optimists who share digestible hope and knowledge to help solve the grand challenges of our times to make the world a better place.[1] TED Talks are made available online in a multitude of languages, proselytising their outlook to anyone with bandwidth and a device to watch them. To use Silicon Valley-speak, TED is both a bug and a feature of our progress-obsessed age.

On stage, I talk about working as a "critical designer" in synthetic biology, an emerging field of genetic engineering. I raise cultural and ethical questions about this technology, invite scrutiny, and suggest art and design as strategies to explore ideas that we don't yet have words for. I have also gone under the lights painfully forewarned that mine isn't a TED Talk. Bruno Giussani, TEDGlobal 2011's curator, has reviewed my script, telling me that I ask too many questions and don't offer enough answers.

My TED experience showed me that to question a technology at the font of techno-optimism, without offering any "actionable" solutions, your approach needs to be clear and your demand even clearer. My talk was never shared. But TED was at least a moment of personal enlightenment: I'm still asking questions.

Eighteen months later, in January 2013, I was preparing for Design Indaba, a major South African design conference that promises "A Better World Through Creativity". Post-TED, I needed to communicate more clearly what I do, and why it matters. Why do I identify as a critical designer, using design to ask questions, not solve problems? What motivates me to stand up in front of people who want to make the world better, challenging their solutions when I have no answers? Struggling, I reached for a plastic bottle of water. As with many designed things, the plastic bottle contains a paradox. Plastic uses less energy to transport than glass, it's safer and stronger and

1 TED Talks on better include Jamais Cascio's (2006) "Tools For A Better World", Geoff Mulgan's (2009) "Post-crash, Investing In A Better World", Jane McGonigal's (2010) "Gaming Can Make A Better World", and Michael Green's (2015) "How We Can Make The World A Better Place By 2030". TED even offers a curated playlist of talks, called "A Better You".

uses less material: by many measures, the plastic bottle is *better* than glass. It's so much better that many of us have learnt to drink water from new plastic bottles, every day, simultaneously creating corporate profit and an ecological horror story.[2]

Design and technology helped to solve a particular problem for industry—light, strong, shatterproof vessels to sell fizzy drinks—and make something better by those measures. But is this better? Who is it better for? The questions are obvious, but I'd never thought to ask them like this, and I'd never heard them asked so plainly. "Better" was the tool I needed to explore the complex questions I struggled to communicate at TEDGlobal, eighteen months previously.[3]

Once I noticed the problem of better, I began to see it everywhere (figures I.1-I.3). Marketers use promises of better to sell everything from beer to chemicals, corporate social responsibility, financial tools, pizzas, and rival political ideologies. Advertisements, propaganda, policies, visions, and utopias are crafted by copywriters, politicians, designers—and even scientists—all promising us a better future. Better can be ours, delivered to us by scientific and technological progress, or by consuming designed things that will better us or the world. But better is not a universal good or a verified measure; it is imbued with politics and values. What better really means to each of us is not as clear as we may assume. And better will not be delivered equally, if at all.

"What is better?", "Whose better?", and "Who decides?" are three seemingly simple questions with immense implications, not just for design or synthetic biology, but also for the way we live and hope to live. This practice-based thesis explores some of the powerful dreams triggered by a banal word, and uses critical design to find new ways to ask better questions of those dreams.

What is Better? Who Decides?

> "...history is a march to a better world."
> —John Gray (2007, p.25).

Better is a contemporary version of the idea of progress, the Enlightenment concept that invited humans to believe that our accumulating knowledge lifts us all, and that we can shape our world towards a future state of imagined perfection. Since progress tells us that things are getting better, things should be better than they have ever been. In many ways, they are.[4] But progress

2 The PET bottle was invented in 1973 to hold carbonated drinks by DuPont mechanical engineer Nathaniel Wyeth. It's not the bottle that's the problem; it's our behaviour. Plastic is not disposable, yet design and marketing have encouraged us to imagine that it is. Americans alone drank a record-breaking 48.5 billion litres of bottled water in 2016, a madness celebrated by industry (IBWA 2017). Persuading us that all tap water is inferior, companies sell water at a higher cost than milk, in containers that we use once. For more on the emergent phenomenon of bottled water, and its different global contexts, see *Plastic Water* (Hawkins et al. 2015).

3 My 2013 Design Indaba talk, "The Dream of Better", is available at https://www.youtube.com/watch?v=CLA4BM6NJas.

4 For examples of contemporary optimism on things getting measurably better, see Moore (2000), Ridley (2010), Pinker (2011), Kenny (2012), and Roser (2014; 2015). Those who believe that cultural and political dreams have failed them and that things are getting worse (even if the world is improving for others),

Figure I.1
Examples of found instances of "better" used to promote all kinds of products and agendas.

Figures I.2-1.3
"Better" fits conflicting agendas. "Securing a Better Future" was the slogan of the UK Conservative Party Conference in September 2014. In April 2015, the Labour Party used "better" to launch their rival General Election campaign.

is not guaranteed, and one kind of progress does not ensure another. Faced with the human-induced catastrophes of the twentieth century, many thinkers relegated progress to myth.[5] Still, ideas of progress seem so embedded in the construction of our world that for many, to abandon them seems impossible. For philosopher John Gray, a critic, progress has become a myth we have to live by. It is "an illusion with a future" (Gray 2004, p.17).

The "dream of better" is an ideological tool fitting for our neoliberal era, stripped of progress's offer to uplift all of humanity.[6] It is a space of promise, of hope, of aspiration, of personal fulfilment, a useful fiction where the world in general, and we as individuals, are somehow improved. We vote, we shop, we learn, we diet, we fight: all for the dream of better. But while better motivates us, we rarely question which better or whose better is being enacted. Better elides *where we are* with where we imagine *we could be*. Yet it has no fixed attributes.[7] Better for some is worse for others.

This flexibility makes better powerful. Within the project of modernity, the common good derives from the well-being of the people; political theory's role has been how to organise and deliver states to improve that well-being. Modern societies have tried to gauge this bettering, but any measurement depends on the measures used (Bowker & Star 1999). These can become entrenched, shaping which better we aim towards, and whose gets delivered.[8] In advanced technological societies like the UK and US, the dominant dream of better has told us that scientific, technological, and economic progress will deliver the public good. Governments and industry often cast technology as the solution to make things better, and innovation—the pursuit of new ideas or products—is promoted as preferable to maintaining what already exists (see Vinsel & A. Russell 2016). But innovation is not a good in itself; its value depends on what is produced (Edgerton 2006).

Better also implies things that cannot be empirically measured, such as hope, optimism, and the moral good. Some philosophers see our proclivity for hope as fundamental to the human condition, manifesting as a yearning for alternatives.[9] This makes optimism—hopefulness about

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and those who feel they are doing better in a worsening world, are still acknowledging the *possibility* of amelioration. For a history of improvement, see Slack (2014).

5 My interest here is not the history of the idea of progress, or whether progress is real, but in the power of aspects of its narrative. For histories of progress, see Bury (1920), Nisbet (2008), Meek Lange (2011), and Harari (2015). For the relationship between progress and evolutionary biology, see Nitecki (1989) and Ruse (2009).

6 Neoliberalism, or free-market capitalism, is a modified form of liberalism in which the market regulates itself and solves problems. It requires reducing interference to markets, and lends itself to the assumption that technologies will be benevolently administered.

7 Better, according to the *Oxford Dictionary of English*, simply means "to improve on", or describes something "more desirable or effective" (Stevenson 2010a).

8 The idea of progress is inclusive: all of humanity should be lifted by it. But better is different. Modern societies have gauged bettering using measures of progress, from economic progress at nation scale through Gross Domestic Product (GDP), or technological progress, through Total Factor Productivity (TFP) (see Gordon 2016). GDP's post-war legacy transformed economic growth into the dominant global driver, without accounting for individual, social or environmental well-being: traffic jams and oil spills benefit GDP, precluding the possibility of well-being for future generations (Philipsen 2015). For a contemporary economic critique, see Piketty (2014).

9 Hope is "grounds for believing that something good may happen" (Stevenson 2010b). Hope, not Freudian

the future—possible.[10] For some, better invokes the "good life", a subjective condition affected by local cultural and political differences, and by nation, class, and religion (Appadurai 2013, pp.187-8).[11] While the common good benefits society as a whole,[12] it is not absolutely better: "goodness is not necessarily moral, nor is morality necessarily good" (Perry 1907, p.145).

These ideas all contain normative demands: demands that indicate how the world ought to be, not how it is.[13] We may assume that the dreams of better offered to us match our own. But promises require scrutiny: as scientists, policymakers, economists, activists, designers, consumers, or citizens, we hold different (and even multiple, conflicting) visions of what better means. We may agree that a better future is desirable, but what that future constitutes is not necessarily shared. No one better can accommodate all humans, non-humans, and the planet.

So how are different betters negotiated? Preferable futures are often defined by powerful actors—political parties or corporations—and offered to us as citizens or consumers, where our limited agency permits us only a choice between them, rather than a chance to challenge them. With the Anthropocene's damaging effects looming, we must question *which* better and *whose* better shapes our common future.[14]

In my doctoral practice and thesis, I use critical design techniques to explore meanings of better. I focus on three fields where better is regularly invoked as justification for action: design, synthetic biology, and their intersection in "biodesign".[15] I investigate the construction and dissemination of the dream of better as a kind of social imaginary, examining how this imaginary

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nightmares, motivate us, argued Marxist philosopher Ernst Bloch (1986) in his influential work *The Principle of Hope*, written between 1938 and 1947, and originally titled *Dreams of a Better Life*. Bloch embraced the human desire for liberation. Hope is not special, it is part of everyday social life, anthropologist Arjun Appadurai (2013, p.289) explains. For more on the anthropology of hope, see Miyazaki (2004), and Zournazi (2002).

10 In 1710, the philosopher Leibniz (1952) concluded that if God created this world, it must be "the best of all possible worlds"; good will prevail over evil. Pessimists have the contrary view. Cognitive neuroscientist Tali Sharot (2011; 2011) asserts that humans are hard-wired for optimism, while conservative thinker Roger Scruton (2010) argues that accepting our darkness is the only way to aspire to social progress; a kind of hopeful pessimism for a better future. John Gray (2007, p.19) also believes such thinking can counter the dangers of contemporary utopianism: "it is *dystopian* thinking we most need".

11 Aspirations to the good life function within a layered system of ideas, Appadurai suggests. Our highest-order social values concerned with life and death connect to a denser layer of local ideas, around health or convenience. These become visible through our mundane desires and choices: the jobs we take or clothes we buy. Our everyday actions let us ignore their enabling higher levels of "normative concerns" (Appadurai 2013, pp.187-8).

12 Utilitarianism was expounded by Jeremy Bentham and John Stuart Mill, who dictated that "actions are right in proportion as they tend to promote happiness" (Blackburn 2016). Bentham believed it should impact on "the greatest happiness of the greatest number" (Calhoun 2002). Utilitarianism is not just an ethical theory: happiness has been equated to economic terms in its modern political use.

13 The normative is "any academic argument that criticizes current arrangements and calls for the creation of a better future" (Mayhew 2015). Normative theory is a point of conflict in the social sciences, as practitioners try to avoid imposing value-judgements in the name of disciplinary objectivity (Castree et al. 2013). I use the philosophical or social scientific meaning of normative throughout, rather than its common meaning as "the normal way to do things".

14 We could abandon better, since it represents progressive ideas of modernity that do not deliver better for all people and the planet. However, in the spirit of hopefulness, in this thesis I choose to work within the frame of better, but I separate it from progress.

15 "Biodesign" has different meanings in different fields. See Chapter 5.

impacts design and, in the case of synthetic biology, how it shapes an emerging technoscience and its own evolving design culture. Dreams of better affect how we see our world; we need new tools to identify and understand these designed fictions influencing our reality. Building on existing critical practice in design, I propose designing "critical imaginaries" to open up our understanding of the values, aspirations, and assumptions that better embodies. I began this project wanting to know how we might design alternative better futures. At its end, I want to use design to understand better, to ask better questions about who designs our "better" future, how, and why.

Sociotechnical Imaginaries, Critical Design, and Synthetic Biology

Sociotechnical Imaginaries

As a powerful space of imagination, the "dream of better" has become so influential in advanced technological societies like the UK and the US that it can be described as a sociotechnical imaginary. I use this term—borrowed from science and technology studies (STS) scholars Sheila Jasanoff and Sang-Hyun Kim—as my first conceptual frame. The sociotechnical imaginary is a kind of social imaginary: the institutions, symbols, and values shared by a social group; society exists through this collective imagining (Castoriadis 1987). As shared, functional fictions, social imaginaries have material impact on our world; examples include money, the corporation as individual, or the nation as political community (figure I.4).[16] The "better future" is a social imaginary, as are fictitious histories like golden ages. Social imaginaries affect the things we design and the science we fund.[17]

16 The imaginary is what we perceive, not just what we make up. It influences how we see and order the world. In *Imagined Communities*, political scientist Benedict Anderson (2006, p.6) cemented the nation as a social construction that exists in our minds. Technological developments like the convergence of printing and capitalism encouraged standardisation of language, fuelling nationalism. Reading the same newspaper as strangers lets us imagine a collective identity, he suggests. In *Modern Social Imaginaries*, philosopher Charles Taylor explains how in western modernity, we legitimate our collective life through the imaginary. An elite produces theories about what the "moral order" should be, but the social imaginary is transmitted by ordinary people through images and stories: it "is not a set of ideas" but "what enables, through making sense of, the practices of a society" (Taylor 2004, p.2). Enlightenment principles tell us that knowledge and solutions flow from the study of reality. But the imaginary is not separate from reality: "'reality' and 'rationality' are its works", philosopher Cornelius Castoriadis (1987, p.3) explains. The psychoanalyst Jacques Lacan (1956) examined the imaginary from the perspective of the mind. Developing Freud's ideas, he described the imaginary, the symbolic, and the real as the structuring order of our existence. For more on the imaginary and imagination, see Lennon (2015).

17 While internal imagination is essential for design, my focus here is the collective imagination. Castoriadis (1987) describes how societies construct mythologies around social orders to make sense of their social existence and means of production. The imaginary transcends individual, subjective representation; it is a cultural ethos through which we organise our behaviours and reinforce relations, the intersubjective lifeworld (Habermas 1996, p.22). For the fiction to survive, we all have to believe in it (Harari 2015, p.127). Imagination is now "an organized field of social practices" and the "key component of the new global order," suggests anthropologist Arjun Appadurai (1996, p.31). Imagination, aspiration, and anticipation are the three human preoccupations that shape the "future as cultural fact" (2013, p.286). For more on the design of political imaginaries, see Duncombe (2007).

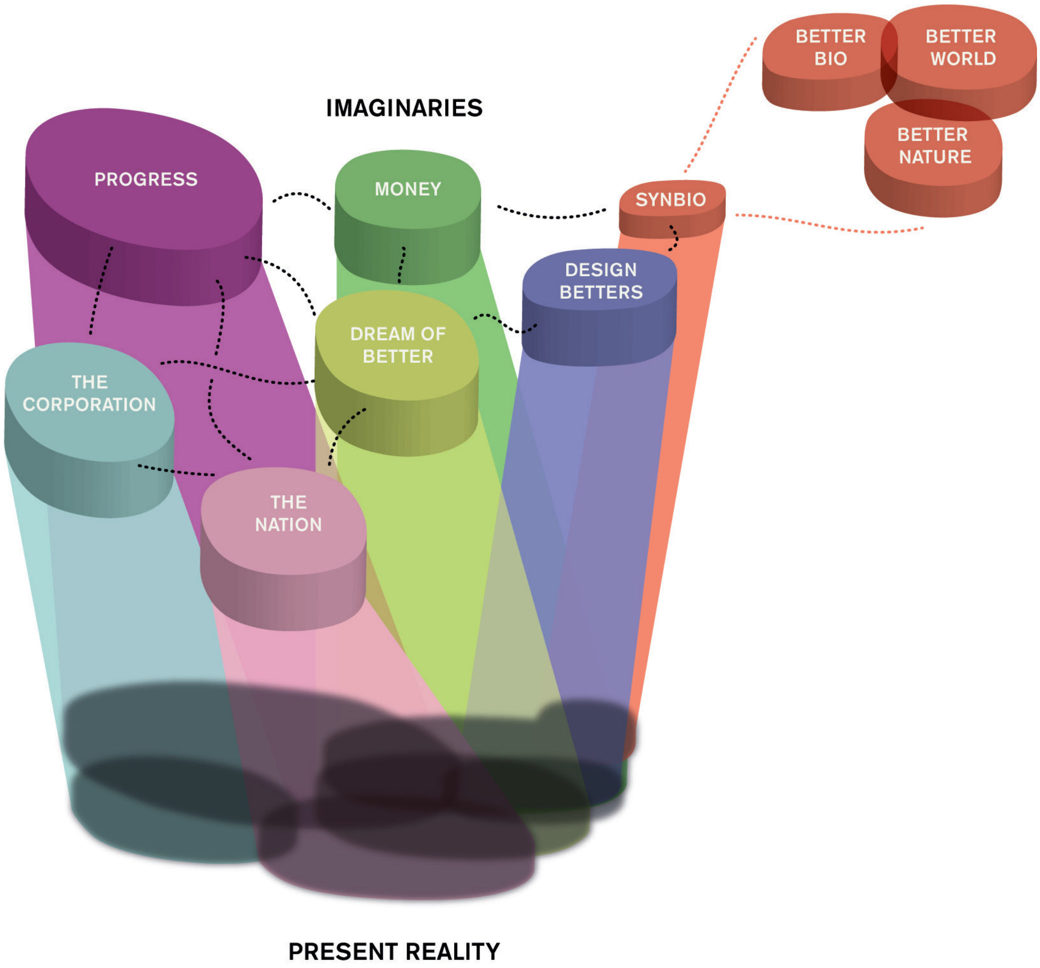

Figure I.4
Social imaginaries are fictions with material effects, shaping our experience of reality.

Sociotechnical imaginaries, more precisely, are "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology" (Jasanoff 2015a, p.4). The concept describes shared visions of social life that enable the realisation of a particular better future through certain technologies, politics, and agendas, especially at the nation scale. Visions originating from individuals or groups—what STS scholar Stephen Hilgartner (2015, p.34) calls visionary vanguards—are embraced by communities, nations, even the entire planet (Jasanoff & Kim 2015, p.7). "Encoding visions of the good society", we can see that science and technology communities are not neutral, but "deeply implicated" in political and social acts (Harvard STS Research Platform 2015).[18] The sociotechnical imaginary is a process for enacting ideologies.

Sociotechnical imaginaries have real effects: visions are imagined, shared, and evaluated by stakeholders, influencing policy and triggering public funding, which enables scientific advances. Since they describe realisable futures and prescribe the futures we ought to realise, sociotechnical imaginaries are normative (Jasanoff & Kim 2009, p.120). They are also self-legitimating: imaginaries that contribute to policies that deliver progress "reaffirm the state's capacity to act as responsible stewards of the public good" (Harvard STS Research Platform 2015).

STS scholars use the sociotechnical imaginary to investigate the relationship between progress in science and technology, and political institutions and power (Jasanoff & Kim 2015). Jasanoff (2015b, p.323) identifies four stages as visionaries' dreams are transformed into reality. First, foundational ideas *originate*, departing from the status quo. Visionary vanguards *embed* these ideas in "cultures, institutions and materialities". *Resistance*, in the form of old or competing dreams, may emerge. Such "resistant imaginaries" can have political strength, such as public opposition to genetically modified organisms. Ultimately, some visions gain traction over others. Finally comes *extension*, as new ideas are taken on, endure and scale, through consumer behaviour, government intervention or other means (2015b pp.322-3). The imaginary contains symmetry, as "scientific and technological ideas... are produced together with ideas about science and technology" (2015b p.333).[19]

18 Enlightenment thinkers' scientific paradigm of experimentation, investigation, and explanation cumulatively built on the findings of others. This "scientific method" improved science's problem-solving ability, bolstering its progress. Science appeared to provide an objective knowledge of reality. Nineteenth-century positivists, like Auguste Comte, promoted these beliefs. But the scientific method shapes reality in its image: we decide what we look at with science, influencing what we know. Research is shaped by funding, contingent on political and economic desires (since the mid-twentieth century, governments worldwide have viewed science and technology as drivers of economic and social progress). STS and humanities scholars are increasingly interested in the imaginary (McNeil et al. 2017). Collective visions at the laboratory scale were described by anthropologist George Marcus (1995, p.4) as the "technoscientific imaginary", whereas Jasanoff and Kim's sociotechnical imaginary operates at a societal scale (Jasanoff 2015a, p.11). Scholars have also looked at the "sociology of expectations" (N. Brown & Michael 2003), and the "wishful enactments of a desired future" (Borup et al. 2006).

19 Co-production is the co-creation of new knowledge by experts and societal groups (see Jasanoff 2004).

In this thesis I explore how better itself functions as a sociotechnical imaginary in advanced technological societies like the UK and US.[20] This tool allows me to articulate "better" as a shared fiction of a desirable future, endorsed by institutions, enacted publicly, and brought to life by collective belief in scientific and technological progress enabling social progress. The imaginary's stages helped me explore better's influence on design, on synthetic biology, and on biodesign, probing how dreams are made in these spaces, whose are implemented, and their political and ideological impact. Identifying and challenging what constitutes the imaginary's "desirable future" is a focus for my critical design work. Sociotechnical imaginaries show how technologies or futures are not inevitable; they are made. This means, crucially, that there are "other worlds are always there for the making"; the same material can spawn "multiple imaginaries" (Jasanoff 2015b, p.339). The imaginary is a designable fiction.

A practice-based design thesis cannot provide a comprehensive history of a concept as vast as "better". Looking to design practice and theory, with reference to art, economics, history, philosophy, science, social science, and STS, I use the sociotechnical imaginary to meet my aims, critically examining the dream of better, expanding my understanding of critical design, developing new critical design techniques to scrutinise "better", and finding ways to communicate these ideas to a range of audiences.

Critical Design

In my practice I use design as a critical medium to engage with the social, political, and ethical implications of designing. This "critical design" is my second conceptual frame. Designer Anthony Dunne introduced the term in 1997 as he sought to expand possibilities for the design of electronic objects beyond innovation. Drawing on a tradition of critical practice to develop new ways to conceive of socially beneficial design, he advocated an approach that is "critical and optimistic" (Dunne 1997, p.1). This thesis takes an intentionally broad view of critical design, unifying art and design works that share this position of "critical optimism".[21] I investigate how this critical design could better explore and challenge assumptions about design or synthetic biology's dreams of better, for different stakeholders. Critical design can problematise our assumptions of better, inviting reflection on what we hope for. Rather than asserting *how* the world ought to be, it can ask *what* ought it to be. Its power is in making space for alternatives, not prescribing what is better.

Similar to my interest in the social imaginary as a tool for critical design, design theorist Carl DiSalvo (2016) suggests "making imaginaries" to ask "what other worlds are possible, what other worlds would we like to bring into being?" DiSalvo takes inspiration from science fiction writers

20 Writing from the privileged location of a postgraduate art and design university in London influences any discussion. While my study is limited to Europe and North America, I hope that future research will examine similar questions for other places and from other perspectives: my aim is to highlight how dreams of better are too often determined in the kinds of spaces I am working from.

21 Dunne proposed critical design as a means for reflection on design, for design. I view critical design as design that reflects on designing, and thus, is a means to explore material culture. I understand critique as constructive and generative, not destructive (see Latour 2004; Calvert & Schyfter 2017). For an overview of critical design practices, see Malpass (2016).

like Ursula Le Guin (2014), who promote writing as a way to imagine other worlds into existence.

The imaginary's framework helps me to examine "better" at a sociocultural scale, connecting design and synthetic biology to influential imaginaries made elsewhere, such as Silicon Valley. There, visionaries also tell us that the better future will be delivered by using technology to solve our problems. Shifting critical design's focus from the downstream implications of technologies (the focus of the Design Interactions department at the Royal College of Art, which Dunne headed, and where I did my MA) to the individuals and ideologies shaping those technologies is an approach Dunne and partner Fiona Raby are also testing in their ongoing "United Micro Kingdoms" research. Used like this, critical design can examine ideologies like techno-utopianism that have a material effect on our lives, laying them open for collective examination and consideration.

"Why question a technology that will better humanity?" techno-utopians ask me.[22] But this isn't technological pessimism, or Luddism; it is critical optimism. Questioning technologies and promises of better transfers agency to individuals. It aspires to more diverse and inclusive dreams.

Building on these insights, in this thesis I propose the "critical imaginary" as a design technique to open up, understand, and encourage the possibility of alternatives. Critical imaginaries can take a variety of forms, from curatorial projects to installations or fictions. They embrace process rather than prescriptive outcomes, referencing Ruth Levitas's (2013) rehabilitation of utopia as a method, not a goal. But the critical imaginary is less a utopia than a heterotopia, the space described by philosopher Michel Foucault (1984) as neither good nor bad, but different. This heterotopic space encourages exploration of betters beyond the existing hegemony, rather than within it. Seeking to decouple better from the progress trajectory, the critical imaginary separates speculation from futures, instead reflecting on the simultaneous realities that are closer to the individual experiences we each inhabit. It can be generative, prioritising complexity and multiplicity over simplifications like better. A critical imaginary for synthetic biology could bring together stakeholders (us all, the planet) to consider a synthetic biology shaped by diverse betters.

Synthetic Biology

Following sociotechnical imaginaries and critical design, my third frame for better is the technoscience of synthetic biology.[23] Instead of inserting single genes into organisms, as genetic engineers have done since the 1970s, in the late 1990s some US engineers began to imagine genetic code as a programming language, DNA as component parts, and biological systems as circuits. Aiming "to make the engineering of biology faster and more predictable, and to

22 Technological utopianism is the belief that technology will deliver the perfect society for all (Segal 1985, p.10). For some, the label is a critique; for others, it is an honour.

23 I describe synthetic biology as a technoscience, combining scientific discovery with technological invention to build useful things. Some of its visionaries came to biology from civil engineering and computer science; today the field includes bioengineers, biologists, chemists, mathematicians, computer scientists, and others.

harness the power of biology for the common good" (Smolke & Silver 2011),[24] synthetic biology's visionaries promise a better world, shaped by their better.[25] In 2016, $1bn was invested in the synthetic biology industry globally (SynBioBeta 2017).

When I first learned about synthetic biology in January 2008 I was curious that its proponents talked about "design". I wondered what would they design? What was good biological design, and who would get to decide? What would designers do in this biotechnological future? Since then I have raised these questions by experimentally engaging with the field as a critical designer, designing fictions, teaching, curating, and collaborating with synthetic biologists, most intensively as Design Fellow on the international research project "Synthetic Aesthetics", from 2010 to 2014. I began this PhD seeking to imagine alternative betters for synthetic biology, using it as a space from which to identify and address broader themes for critical design, and understand its own relationship to better.

Methods

PhDs by project are dialectical processes, shifting between practice and more traditional research methods. This presents its own challenges (see Yee 2007). The emerging field of design research has shown an aspiration towards more scientistic methods to formalise techniques for knowledge production (e.g. Zimmerman et al. 2010).[26] However, interaction designer Bill Gaver (2012) argues that standardising practice can shut down possibilities unique to design. Design is unlike science; there is no one, best design, but multiple simultaneous possibilities. He suggests embracing design's generative and contingent qualities. Similarly, rather than offering a social science study of my exchanges with synthetic biologists and publics, or a quantitative analysis of data generated through those interactions, this thesis is qualitative and exploratory, eliciting questions and subjective insights. This approach helped to reveal what better means to those who get to decide.

Christopher Frayling (1993), cultural historian and educationalist, differentiates between research *into* design (such as the work of historians), research *through* design (materials and processes, for example), and research *for* design, where thinking is "embodied in the artefact". My work encompasses all three, as research and practice merge: my critical design practice informs the thesis and vice versa (see Appendix A for my PhD timeline). My interventions in synthetic biology and its politics—reflecting the subject's live nature—developed my thinking and practice, and helped me to identify synthetic biology's proliferating meanings of better. Leading with practice allowed me to reflect on it afterwards, but design and theory are not

24 Synthetic biology's definition has been debated since the outset. I start with the description used on the synthetic biology's community website since 2005, as it represents the field's founding vision: "A) the design and construction of new biological parts, devices, and systems, and B) the re-design of existing, natural biological systems for useful purposes" (OpenWetWare 2017).

25 Synthetic biology's visions are being led by the US, Europe, and China, but it is not a "first-world issue". The technologies it has produced so far, from engineered mosquitoes to antimalarial drugs, are being deployed in developing nations. Promised technologies being invested in by Silicon Valley's elite, such as human genome editing, could serve to heighten inequality. This is a global concern.

26 For more on design research methods, see Rodgers & Yee (2015); Vaughan (2017).

separate: writing is practice too.[27] My design projects demanded literature reviews of their own; their public exhibition, dissemination, and discussion informed my analysis and directed further reading across different disciplines, which instigated new action. Further research led me to classify the dream of better as a sociotechnical imaginary, to use its framework to structure my research into examining better, and to review critical design and biodesign in this context.[28] This process deepened my understanding of each project, of critical design and, ultimately, of better. The concept of the critical imaginary emerged from final reflection.

Navigating the field of synthetic biology and establishing experimental collaborations has been part of my practice and research. I set out wanting to test how critical design could play a useful role "upstream" in the development of a technology, where visions are being designed by synthetic biology's vanguards, policymakers, industry, and "downstream", with the media and publics.[29] In 2013 and 2014 I developed different kinds of collaborations with synthetic biologists and their institutions, including the International Genetically Engineered Machine competition (iGEM), Warwick Integrative Synthetic Biology Centre (WISB), and the Synthetic Biology Innovation and Commercialisation Industrial Translation Engine (SynbiCITE), at Imperial College London; and with cultural institutions including Science Gallery Dublin, and London's Victoria and Albert Museum (V&A). These ranged from self-initiated, independent projects with synthetic biologists as consultants to working inside the field. Relationships were specific to each project and its origins, and affected the outcomes. Some projects were successful; others, troublesome.[30] These interactions showed me that my interest is not just the technoscience, but also the construction of fictions that shape it. I realised the role of conflict in my critical design practice: my projects draw on clashing ideologies, questioning ambitions, values, and practices. By "staying with the trouble", as STS scholar Donna Haraway (2016) advocates, my practice finds, learns from, works with, and makes trouble.[31]

My critical design methods include designing speculative fictions and workshops and curating. The appropriate media, collaborations, and scale depend on the project. The practice also includes what are best described as interventions: publishing opinion pieces (e.g. Ginsberg

27 Making my writing accessible to different audiences with varying expertise is an act of communication design and part of my practice, and affects my stylistic choices. As a practitioner, I perhaps also place different emphasis on visual artefacts and imagery than other humanities scholars might, whether amassing evidence of better in street advertising and posting it on Instagram (see #dreamofbetter), or analysing images to inform my own aesthetic choices, and drawing on those choices to analyse others' work, such as scrutinising glowing trees made by scientists or designers.

28 I used Jasanoff's stages of origins, embedding, resistance, and extension to research synthetic biology's imaginaries. The chapters reference these concepts but are not organised using them; each follows a different structure as findings dictated.

29 I distinguish my work from "public engagement", an official process to disseminate knowledge and encourage dialogue about scientific research. Since synthetic biologists aspire to public acceptance, I found that in practice, engagement is seen as a tool to enable acceptance. See Chapter 5.

30 Due to collaborative difficulties, I cancelled one project, a proposed conference in 2014 on synthetic biology, art, and design at the Museum of Modern Art, New York, planned to launch the *Synthetic Aesthetics* book.

31 Haraway (2016) advocates a non-anthropocentric approach of "staying with the trouble, and "becoming-with-each-other" to address our human-made environmental catastrophe. Like Bruno Latour (2016), she suggests we remain "earthbound". At the same time, Haraway encourages "speculative fabulation" for world-making, as a strategy for amelioration.

2015), or giving interviews for different audiences; giving talks to synthetic biologists, designers, policymakers, and the general public, and interacting with synthetic biology's vision-making machine by joining internal visioning workshops. Practising in public can be troublesome, but it offers rich opportunity for progressing ideas by revealing differences in agendas and understanding.

Building these collaborations, analysing their outcomes, and writing about synthetic biology requires sustained engagement with the field and research into it.[32] I draw on conferences I attended, academic literature, media, social media, correspondence, and conversations with those involved until my research cut-off point in May 2017.[33] To analyse my projects I reviewed notes and correspondence, recordings, photographs, media reports, and comments, and tracked how my ideas infiltrated the technoscience. The sheer speed of change in synthetic biology is an integral feature of the topic that impacts on my practice. The challenges I faced draw parallels with contemporary history and ethnography.[34] Whether it is even possible to work critically from "inside" is a fundamental concern discussed in Chapter 5.[35]

Structure

Six chapters investigate the workings of the imaginary of better within design (Chapter 1), synthetic biology (Chapters 2-4), and its effects on interactions between the two (Chapter 5). Chapter 6 sets out the design of critical imaginaries as a technique for investigating dreams of better. Analysis of the six projects and other interventions that informed the writing and research is integrated throughout the thesis; detailed processes are located in the appendices.[36]

"Better by Design" (Chapter 1) teases apart how better functions within design, to understand critical design's relationship to better and contextualise my work in synthetic biology. It explores the influence of better on design, and how design has reinforced certain betters.[37] Design

32 Engaging with biological material usefully implicates the artist in its use, as advocated by bio-artist Oron Catts, director of the art science laboratory SymbioticA at the University of Western Australia. Since I am clearly implicated in the field of synthetic biology, I have so far chosen not to exploit living things in my work when methods like fiction can work. However, I have spent time in the laboratory practicing genetic engineering techniques. In 2008 I spent a week on a SymbioticA laboratory workshop led by Catts; in 2009 I joined a two week "crash course" in synthetic biology with the University of Cambridge iGEM 2009 team, followed by a three month residency at SymbioticA, spending time in Plant Sciences. In 2011, Catts and I developed "Synthesis", a one-week synthetic biology course in John Ward's laboratory at University College London, with Arts Catalyst, funded by the Wellcome Trust.

33 My involvement, research, and practice in the field continue.

34 My descriptions of my practice share some similarities with autoethnographic methods. Combining aspects of autobiography and ethnography, autoethnography uses subjective accounts to connect to broader cultural, political, and social issues (see Adams et al. 2014). However, since my explorations are of synthetic biologists' dreams of better—not my own—they are not autoethnographic.

35 Journalist Timothy Garton Ash's (1999) *History of the Present* describes the finely wrought balance between clarity and distortion of the eyewitness to history's unfolding.

36 Due to space limitations of a practice-based PhD thesis, I have included only the pertinent details and findings of projects within the chapters.

37 In this thesis, I use "design" to refer to a process (to design) and to the things that are designed through

embodies the desire for change, what sociologist Richard Howells (2015) describes as design's utopian impulse. The chapter classifies design as an optimistic activity. This includes critical design, which works to alternative betters than consumerism. It argues that critical design's intrinsic optimism can be separated from engineering and market-led ideas of the optimum and optimisation that shaped mainstream design in the twentieth century and today.

Chapters 2-4 investigate how the dream of better has informed synthetic biology's own emerging imaginary, from its beginnings in the late 1990s until early 2017. With little precedent for design beyond its engineering definition, synthetic biology has been a valuable space for me to define, test, and expand critical design's potential since 2008. Working in a young field let me watch how people and their values, economics, and policies shape a technology, and see how imagination can tip speculation into reality to create a field. The sociotechnical imaginary's stages—origins, embedding, resistance, and extension—informed my analysis of better's proliferating meanings, helping me understand how these are imaginaries constructed, by whom and to which values.

"Better Biology" (Chapter 2) examines the ideas of better that synthetic biology was founded on from 1999, when engineering ideologies were mixed with open-source values borrowed from early Silicon Valley. I introduce the iGEM 2014 Art and Design Track and Prize, which I designed and chaired with synthetic biologist Christina Agapakis, and a failed collaboration with WISB, where scientists sought to develop a resistant imaginary defined by a biological (not engineering) paradigm. These troubled projects provided insight into interacting with others' imaginaries of better.

"Better World" (Chapter 3) analyses how synthetic biology's dreams of better evolved from 2006, when a better future built using this better biology began to seem possible and lucrative. This vanguard promulgated an imaginary where industry "re-couples" with nature to deliver a better future of sustainable abundance. Borrowing Silicon Valley's enthusiasm for "disruptive innovation" and "solutionism" gave this dream traction. But resistant ideas of better soon challenged it. I discuss "Alternative Roads", my workshop and report for SynbiCITE's synthetic biologists, which informed *Design Taxonomy*, my installation commissioned by *Dezeen* and MINI. These projects explored the imaginary of sustainable abundance and tested designing alternative visions of better as critique.

"Better Nature" (Chapter 4) follows a third better that is rapidly advancing with the technoscience. The dream of bettering "nature"—so that it may no longer exist—is manifesting in biological designs as synthetic biologists try to change our nature, to eliminate species, and make a "damaged" nature better. I examine the unlikely convergence of synthetic biologists' and conservationists' dreams of better through *Designing for the Sixth Extinction*, my critical design fiction. The vanguard's advance, despite the complexity of biological intervention (which policymakers are struggling to comprehend), reveals a modernist ideology. Can critical design aid reflection on the impossibility of a universal better, for humans, other organisms, and the planet?

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that process (designs). Design varies by place, attitude, and individual, covering a breath of approaches that define better differently. The industrial designer may try to eliminate the unexpected, while a fashion designer seeks it out; the sustainable designer may prioritise opposite values to conventional practitioners.

With these imaginaries identified, “Critically Designing Biology” (Chapter 5) analyses design’s critical work on and in biological design. I examine how synthetic biology and design are engaged in a mutual colonisation of each other’s dreams of better that risks eliminating space for critique. Critical design can still carefully navigate imaginaries to trouble them, but to do this well requires rejecting the linear model of technoscience “upstream” from society. I argue instead for technoscience *framed by* society.

In “The Design of Critical Imaginaries” (Chapter 6), I propose a technique to generate alternative perspectives on better, providing a heterotopian space of imagination away from progress’s linear trajectory. Chapter 6 revisits my projects, and discusses “Grow Your Own... Life After Nature” (GYO), a major exhibition on synthetic biology at Science Gallery Dublin, for which I was lead curator, and the “V&A Friday Late: *Synthetic Aesthetics*”, a one-off “biological takeover” of London’s Victoria and Albert Museum, a public event for over 4000 people that I led the programming of to launch the *Synthetic Aesthetics* book (Ginsberg et al. 2014).

Summarising my findings about better, I conclude with future directions to explore in designing critical imaginaries. Seeking to better critical design practice while critiquing better may seem paradoxical. But critical design is fundamentally optimistic. It seeks alternative betters; that is its internal conflict. Working with synthetic biologists, social scientists, media, and industry, I learnt that while we can’t assume a universal definition of the common good, critical design is a powerful mediator between agendas and could help articulate and negotiate diverse dreams. In “better” I found a critical tool to communicate why design should ask questions of our complex world, not just offer to solve its problems.

Figure 1.1
A foundry in the Suame Magazine, Kumasi, Ghana.

Figure 1.2
“Turtle 1” (2013) proposes an alternative, better way of making things. Working with the Suame Magazine community in Kumasi, Ghana, Melle Smets and Joost van Onna intended to make a prototype car for the African market, designed to afford a great view of the landscape and be robust and easy to repair.

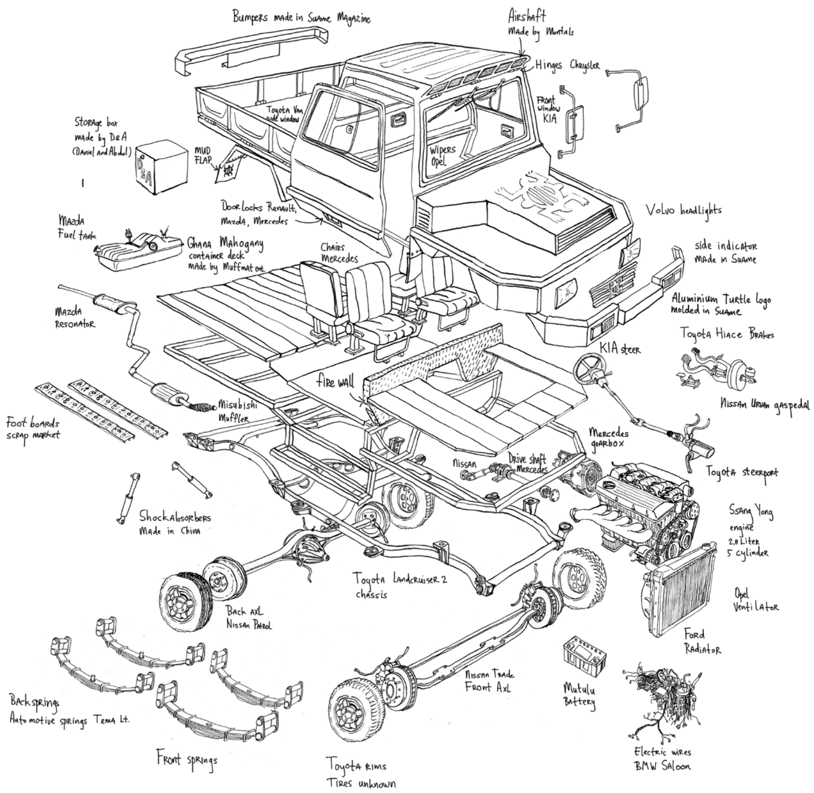

Figure 1.3
Smets’s components diagram (2014) showing scavenged parts from imported vehicles used for the Turtle 1’s engine and chassis.

Chapter 1. Better By Design

1.1 Introduction

Holding the cheerfully yellow book in both hands, I stared at its equally hopeful title: *31 Brilliant Ideas FOR A BETTER WORLD*. I was trying to make sense of how the twenty-ninth idea, my critical work *Designing for the Sixth Extinction*, fitted the theme (van Lier & Nolan 2015, pp.78-9).[1] My project uses fiction to explore synthetic biologists' very real proposal that human-designed organisms could be released into nature, to save it (see Chapter 4). But I wouldn't suggest my response as a brilliant idea for a better world. And I never meant for it to be a solution. This incongruity between the book and my project revealed critical design's complicated relationship with better. Even if I prefer questioning and poetic exploration to problem solving, have I really escaped design's solutionism? Does critiquing an issue belie an impulse to make things better? To make sense of my critical design work in synthetic biology, I need to unravel design's relationship with better.

Engineers have formal ethics that codify their work as doing good for society (e.g. Royal Academy of Engineering 2014), and architecture embodies ethical choices (Lagueux 2004), so it's often assumed that designers are also driven by the common good.[2] MoMA design curator Paola Antonelli has described this as design's "Hippocratic oath" (Ryan 2015, p.67). But this imaginary of bettering is challenged by a place like the Suame Magazine in Kumasi, Ghana. Here, 200,000 people in 12,000 informal workshops craft spare parts, and chop, weld, and hammer vehicles and scrap back into local circulation (Jaarsma et al. 2011). Reconfiguring European-designed components, the mechanics reimagine the used into the useful (figure 1.1). We easily declaim planned obsolescence, but its reality is more complicated. If mainstream Western design has become synonymous with a particular imaginary of better—driving consumption with a flow of new and better things—its shocking waste provides material for Suame's artisans. But progress is now endangering the area's future, as new vehicles threaded with electronic components threaten to obsolesce its ecosystem (Yeebo 2014). Can we really accept that designers (and engineers) automatically make better things for a better world?

This trouble with better is my starting point. Rather than offering an objective or historical investigation into design, this chapter contextualises my practice by considering critical design's complicated interaction with better. To do this, I examine three ways in which better influences

1 The book was compiled by the Dutch design conference What Design Can Do!, where I gave a talk in 2014. In 2015, the organisers commissioned a new edition of *Designing for the Sixth Extinction* for their special exhibition "What Design Can Do" in 2015 at Amsterdam's Stedelijk Museum.

2 Architecture also has professional codes, e.g. provided in the UK by the Royal Institute of British Architects (2005). The World Design Organization (2017) provides a "Code of Professional Ethics" for industrial designers, but designers are not professionally certified like engineers or architects.

design. The first is design's optimism: the desire to make the best of all possible worlds. Do better things better our lives? The second is the fiction of the optimum: does design really make better things? And thirdly, how do we choose which thing is better? Designers may solve a brief through a process that engineers call optimisation, identifying the best world between those available. Does this prevent imagination of other possible worlds? I use these frames first to highlight designs that endorse the dominant imaginaries of better, and then consider critical designs. Doing so clarifies my position relative to better and design, and informs my critique in later chapters of synthetic biology's own emerging design culture.

Design can't exist without the dream of better: optimism is intrinsic to the act of designing; even critical design is optimistic. But designs are influenced by the "conditions of their making" (Forty 1986, p.7). As things with social lives, the values embodied in designs enable their exchange as commodities (Appadurai 1986). And those values, as with better, aren't fixed. Designers give form to social imaginaries, perpetuating them through designed ideas, which inform ideas about design. By adopting the fiction of the optimum and optimisation's constraints, mainstream design has reinforced the market's values of better.

Design can work to other betters. In 2013, Dutch artist Melle Smets and sociologist Joost van Onna (2016) worked with the Suame Magazine community to design a robust African concept car. Drawing on local craftsmanship and reuse, the "Turtle 1" car tapped the waste stream for parts (figure 1.2-3).[3] The one-off was described as the first car ever designed and produced for export from the region to the West, reversing entrenched flows of expertise and goods. Turtle 1 used design critically and optimistically to question better, bringing attention to aspects of our consumption system often hidden in the West (see Debatty 2014). But Smet's dream of an alternative local car brand ultimately failed, the victim of diverging dreams of better.[4] Critical design can play with the optimum and optimisation, as Turtle 1 did, or it can abandon them.

This chapter defines critical design broadly, including work that brings attention to or challenges dominant imaginaries; that dreams of, embodies or precipitates alternatives, or that reimagines design's role in bettering. Design's tradition of critical practice is not extensive like that of art or architecture.[5] But practitioners do examine "better", critiquing design, or using design to critique society (Mazé & Redström 2007).[6] Instead of solving problems, this design makes problems—including its own, like the Turtle 1's—visible. This chapter establishes critical design as a material- and discipline-agnostic approach, based in non-optimal, non-optimising, critical optimism.[7]

3 SMATI, the Suame Magazine Automatics Technical Institute, was a project partner. After exhibition in 2014 in France and the Netherlands, the prototype returned to Ghana for official handover to the community.

4 The project's collapse is complex. SMIDO, the project's local development partner, was using the story to attract funding for a robotic manufacturing plant, while Smets and van Onna had a different idea of better, pursuing a small production line (see Smets et al. 2016).

5 Speculative work is more commonly used to stimulate new ways of thinking in architecture than design. From the radical 1960s architectural groups like Archigram or Archizoom to leading practitioners like Peter Eisenman, Zaha Hadid and Rem Koolhaas, some architects weave speculative projects, theory, and built work through their practice.

6 The nineteenth-century utopian efforts of William Morris could be described as a critical use of design.

7 Outputs include: exhibitions, events, images, installations, fictions (futures, alternative presents,

1.2 Optimism: Design Betters The World

Do better things make a better world? Since design gives form to material culture, communicating its values, design clearly isn't nihilistic. Richard Howells (2015, p.1) describes human creativity as a utopian impulse: we use design to express our "drive to make a better world". Building a house or weaving a blanket involves synthesising existing materials into new things.[8] Using design to seek the best of all possible worlds means optimism is at its philosophical core.

This hopeful and constructive interpretation reveals design's intrinsic "good". But what that good constitutes is less fixed. Progress implies that we map out our lives, working to achieve a state of future perfection that we imagine (Gray 2013, p.111). Design can help us reach that future, since it is bound up in normative demands: political scientist Herbert Simon (1988, p.67) described design as the process of planning to change "existing situations into preferred ones". But whose preference is being gratified, and at what cost to others? Design's power to communicate ideas means that we often neglect to interrogate *which* or *whose* better it is in service to.[9] Design is a matter of politics (Margolin 2002; Fry 2011). So whose better world are designers making?

The Modernist Better

In the twentieth century, progressive designers presented design as a mechanism for social change, a means to deliver the greater societal good. Design had emerged from the Industrial Revolution to service industry: applied artists styled mass-produced goods to differentiate them from others, galvanising the growing consumer culture and aligning design to commercial values.[10] Reacting to some of these "bad" nineteenth-century design practices, social reformers and designers in the early twentieth century began to attach a moral priority to design: better things would better social conditions. Design gave form to their social ideologies and their political, economic, and (pseudo) scientific reasoning, materialising the utopian visions of the modernist agenda (Wilk 2006).

In Europe, the modernists sought high culture in design objects, promoting a moralising orthodoxy around "good" design (Forty 1986), embodied in the mass-produced output of the Deutscher Werkbund collective, or in the dream of the house as a "machine for living in" (Le Corbusier 1931). Honest form and hygienic design would better society; bad design was a culturally degenerate waste of labour and materials.

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counterfactual histories, utopias or dystopias), films, hoaxes, material studies, objects, performances, products, prototypes, publications, simulations, start-ups, talks, websites, and workshops. Critical designs can act as provocations, or commentary, or both.

8 Understood like this, all of human history and its constituent activities could be "rewritten as a history of design", suggests anthropologist Arjun Appadurai (2013, p.254).

9 Guy Julier (2008, p.17) argues that we need to scrutinise design culture; only by understanding the current state of design culture "can we then begin to look at routes towards its ethical and practical amelioration".

10 The Royal College of Art started in 1837 as the Government School of Design, placing design in the service of industry.

A very different approach emerged in the US. After the financial crash of 1929, designers including Norman Bel Geddes, Walter Dorwin Teague, Henry Dreyfuss, and Raymond Loewy elevated industrial design from styling to profession, promoting it as a way to fix an economy suffering from what corporations saw as drastic under-consumption (Meikle 2001; Andrews 2009). They adopted the nineteenth-century design practices that the European modernists were reacting against; soon, new and constantly updated goods poured into the marketplace, each purposefully designed to be a little better than their predecessor.

These designers exploited our yearning for a better world. The designer as taste-maker could manufacture desire, tapping into what designer Natalia Ilyin (2006, p.14) calls our "addiction to perfection". As an act of planning, design not only projects into the future, it exists because of its very possibility. But the future is not just an empty possibility space that we beam designs into (Mazé 2014, p.1). The things we produce populate the future, but a future we imagine also populates them. Design oscillates between past, present, and future. Things must be imagined to become real: designers configure products, architects plan houses. But "by the time a building is built, the reality it was constructed to respond to has changed", observes Ilyin (2006, p.74). This lag, and the disappointment—and hope—it created, was exploited by the industrial designers of 1930s America. Soon, "the present seemed capable of gratifying every desire, but Americans did not lose sight of the future. The daily increasing flow of new products engendered belief that the good life would continually grow better" (Meikle 2001, p.8). Stimulating the US economy, planned obsolescence contributed to a particular idea of the common good.

Infusing design with market values and social dreams, the early American industrial designers cemented design's role in capitalist, material society, while—like the European modernists—promoting a moralising social improvement. They saw themselves as both salesmen and "social engineers designing and controlling a machine-age environment" (Meikle 2001, p.133). Increased efficiency and productivity would generate progress, expressed through the flow of streamlined novelty (e.g. Geddes 1932).[11] Their fervour had a darker side: design historian Christina Cogdell (2004) has looked at how these men were influenced to different degrees by eugenic beliefs rooted in social Darwinism and neo-Lamarkism.[12] Consuming their designs would better the human race (a harbinger for synthetic biologists' design dreams in Chapter 4).

Operating mostly under corporate patronage, the early twentieth-century industrial designers still celebrated the illusion of "direct social control" (Meikle 2001, p.133). This mirage became part of design's conflicted rhetoric of bettering. Ilyin (2006, p.51) sums up the symbiosis: "Sometimes designers have used industry as a way to make their ideas real in the world. But sometimes [...] industry has used designers to make its purposes look ideal". Eventually, over-consumption would become a problem that design helped to make, but couldn't solve. Yet this better—a mix of moralising control and consumption—still shapes mainstream design today.

11 We still think about design like this, believing that well-designed tools reduce friction in our lives, improving efficiency to generate economic growth. But those tools don't automatically equate to a better life: email makes work more efficient so we can work more, not less.

12 Social Darwinism dictates that progress is a law of nature and society follows rules of natural selection. In biological terms, success is accounted for by the numbers of copies of a species. Social Darwinists peg the natural ability to survive to goodness itself. The concept was popularised in the nineteenth century by theorists like Herbert Spencer (1860).

Other Betters

Design can work to politically different ideas of better. In the early 1920s, Russian Constructivist artists imagined "socialist objects" that would convey socialist values instead of fuelling capitalism's commodity fetish. Artists, including Aleksandr Rodchenko and Varvara Stepanova, designed industrial objects, clothes (figure 1.4), and even adverts as "coworkers" that would play an active role in social life as tools for socialism (Kiaer 2005, p.37). They didn't deny the place of these objects in modernity, nor the power of mass-produced goods; the objects had to straddle this contradiction (2005, p.1). From 1962, designers at the All-Union Scientific Research Institute for Technical Aesthetics (VNIITE) continued to use design to explore non-capitalist values and try to centrally plan design (figure 1.5) (Cubbin 2016).[13]

Designs also don't have to be commodities. Vladimir Arkhipov collects items made behind the Iron Curtain that form "part of that special class of functional objects in the world that were not made to be sold" (McGuirk 2012). These designs make life better for their users, whether a home-made bath plug or a TV aerial made from forks (figure 1.6) (Arkhipov 2006). Shaped by political, historical, and economic parameters, they remind us that design is not defined by being mass produced, bought, or sold.

Contemporary hacker, maker, and repair subcultures use design to embrace decentralisation, prioritising values like citizenship over consumerism. For example, the Fixperts (2016) community encourages makers to mend, invent, and modify designed things for others (figure 1.7). Some use design to political aims: Platform Cooperativism (2015) resists commodification of the internet, designing alternative spaces online. Coopify is a smartphone application designed to make the sharing economy fairer for low-income workers (Quart 2016), while Transactive Grid uses blockchain technology to allow New Yorkers to buy and sell renewable energy to and from each other (Rutkin 2016). These critically engaged products are not unequivocally better—and they still operate within capitalism—but they aspire to give choice over how we consume and in which forms of power we invest and participate, using design to make those decisions accessible (see Slavin 2016). Better for these designers means democracy and transparency.

Believing that other, better worlds are possible, we use design to bring those worlds into existence, whether capitalist or critical, resistant dreams. These examples remind us that design is always optimistic, regardless of which world it is used to imagine.

13 For example, VNIITE designers investigated how "information-age socialism" could manifest in the home (Cubbin 2014).

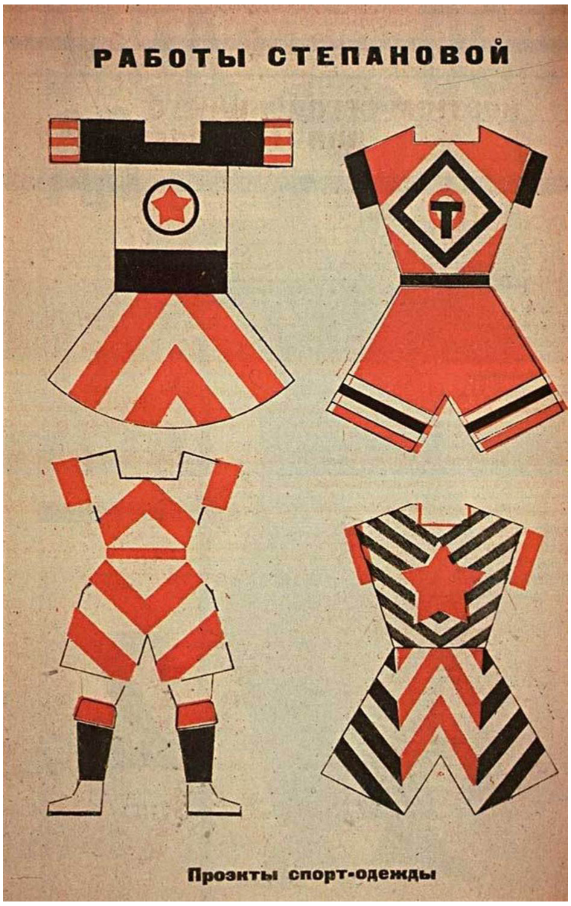

Figure 1.4
Constructivist artist Varvara Stepanova's socialist sports clothes (1923) are an example of design working to agendas other than capitalist consumerism.

Figure 1.5
This prototype BelA3-540 truck (1965), designed at VNIITE, was part of its effort to centrally plan design. From 1962, this Soviet institution grappled with the problem of raising living standards whilst rejecting capitalism's consumerism and planned obsolescence. It closed in 2013.

Figure 1.6
Things don't need to be sold to be designs. Vasilii Arkhipov, father of folk artefact collector Vladimir, apparently created this television aerial in 1993 from surplus forks bought by his mother when other goods were in short supply (Arkhipov 2006, p.149).

Figure 1.7
Fixperts dispels the definition of design as mass-produced commodity. Volunteers Dan Jackson and Sophie Both created this "sockhorn" (2013) for "Fixpartner" Edna Day, who had trouble putting on her socks.

1.3 Optimum: Design Betters Things

From Better to Best

Designers may dream of a better world, but does design really make better things and if so, by what measures are they better? Committee's *The Last Man's Seat* (2013) (figure 1.8) imagines the last individual in the world, free of constraints, generating endless variations on his perfect chair. Design can be subject to technological improvement, but it is not progressive: the last seat is not necessarily the best. The optimum is a design fiction that reinforces a particular imaginary. It tells us that there is a single best solution that we must strive for, whether determined by political or ideological reasons.[14]

Some designs may be widely judged to be superior to others, but design is never optimal because desires and contexts are diverse and changing. We evaluate design using objective metrics as well as subjective ideas. The no-frills John's Phone does less than a smartphone, but you may prefer its ironic simplicity (figure 1.9). Designs aren't isolated objects; they can't function without context. But designers too rarely consider this context: not the "blank space between things" but, as Appadurai (2013, p.264) explains, the "space that generates meanings by generating real and possible relationships and intended and unintended effects for viewers and users". Even when we "design contexts for objects", they are still "subsequently sold as self-standing" (2013, p.263). And object-centric values (aesthetics, price, functionality) often trump contextual conditions (raw materials, labour, durability, disposal). By ignoring context, designers—and consumers—have contributed to socially, economically, and environmentally destructive activities, like prioritising plastic bottled water over water infrastructure. One person's better may make things radically worse for other people, organisms, and the planet. Neglecting context, even socially aware "design for better" can be bad. The mediagenic PlayPump (figure 1.10) appeared to make extracting water fun; but it transformed play into child labour (Borland 2011).

Design is used in contexts, by people. Paola Antonelli and Jamer Hunt's (2015) curatorial project *Design and Violence* identifies designs that embody this subjectivity, like the "Liberator" (figure 1.11), the first 3D-printed gun whose design files were shared online (Walker 2013). Designs don't have agency, their commissioners, designers, and consumers do. But designs are not neutral. Political theorist Langdon Winner (1980) argues that artefacts embody politics either by having features that can implement certain agendas (intentionally or unintentionally), or by being "inherently political technologies", which require, or are at least strongly compatible with, certain politics. We decide as society which applications are moral, but goodness can be contingent and subjective. A drone is a "dual-use technology" than can deliver aid or death. Yet despite changing contexts and people making the optimum impossible, mainstream design—and synthetic biology, as we will see—still promise the best.

14 For design theorist Jan Michl (1990), this fiction of the best design was a "prop" of the modernist visionaries.

Figure 1.8
Committee's stop-motion animated film *The Last Man's Seat* (2015) encapsulates the fictional status of the optimal design. It is part of Committee's ongoing work imagining the "last man" who, free of obligations and constraints, sets about materialising his perfect world.

Figure 1.9
John's Phone (2010), by Hein Mevissen and Diederiekje Bok of creative agency John Doe, offers an ironic commentary on the idea that better means more. Their ultra-basic device includes pen and paper on the rear face for storing numbers.

Figure 1.10
Celebrated in international media, design awards, and humanitarian campaigns with photographs of children playing while extracting water, Ralph Borland's (2011, p.158) photograph of an installed PlayPump shows the reality: a design for good that turns play into labour, is expensive to maintain, and uses a flawed model of advertising to rural communities to fund maintenance.

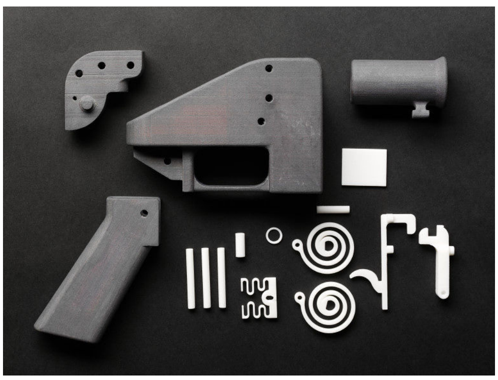

Figure 1.11
Even if democratically distributed, design is not intrinsically good: goodness can be contingent and subjective. In 2013, Cody Wilson, a Texan law student, shared design files online to allow anyone with access to 3D printing to produce a copy of the "Liberator", a functioning gun.

The Non-Optimal

Challenging the optimum's primacy opens up avenues for critical investigation. Architectural writer David Gissen (2009) proposes "subnature", a suboptimal category of nature. This includes the dust, smoke, and weeds produced by society that exist alongside the "nature" we idolise, like trees or sunlight. Bringing subnature into awareness is not to fetishise it, ignore it or design it out, but to accept it. Revealing the urban condition, it can be used critically yet optimistically, as in new-territories and R&Sie(n) architects' B_mu museum tower proposal for Bangkok (figure 1.12). Its façade would accumulate pollution to protect the rarefied gallery space inside. This dialectical quality connects the user with the ideologies shaping the object. Unknown Fields' *Rare Earthenware* (2014-15) vases are also subnatural (figure 1.13). The vessels were made from radioactive soil collected from an Inner Mongolian lake, polluted by a refinery processing rare earth metals for smartphones and laptops (Unknown Fields 2016). The toxic vases must be isolated from the viewer, literally separating design from context. They make us ask: "How is this the best of all possible worlds?"

Conversely, the "post-optimal" is a fictional category for electronic objects that have reached optimal "technical or semiotic functionality", suggested by Anthony Dunne (1997, pp.22-23). It allows the designer to focus on ideas beyond function: aesthetics, poetics, and experience. Dunne's post-optimal, like the optimum, is a fiction.

Abandoning the optimal entirely, artist Ai Weiwei instead makes "useless" objects by repurposing designed things into politically charged artworks with narrative woven into them (Bracker 2015, p.9). His marble *Surveillance Camera* (2010) is functionally non-optimal (figure 1.14), but the delicate, reassembled *Table and Pillar* (2002) is still usable (figure 1.15). Revealing political tragedy and loss, both works give hope through humour and artistry. These communicative objects are not passive; they bring awareness to the political. They use design not as a tool for change, but to call for change, encouraging us to believe another world is possible.

Design *can* make better things, but that better depends on people and contexts. We can never achieve perfect things, only the possibility of better ones. However, the optimum implies that there is no alternative. Challenging this fiction, critical designs can open up the search for alternatives.

Figure 1.12
new-territories/R&Sie(n)'s proposed B_mu Tower (2002), Bangkok, Thailand, is an example of non-optimal design. This conceptual model suggests electrostatic forces "breeding" particles over the façade, rendering pollution visible while filtering it out to create a rarefied space for the museum inside.

Figure 1.13
Rare Earthenware by Unknown Fields (Liam Young and Kate Davies) (2014-15). These non-optimal vases are made of black stoneware and radioactive mine tailings.

Figure 1.14
Ai Weiwei's marble *Surveillance Camera* (2010) is technically useless, but functions as a narrative object with politics and stories embedded in it.

Figure 1.15
Ai Weiwei classes his still-functional *Table and Pillar* (2002) as "useless objects" that no longer fit their original purpose.

1.4 Optimisation: From Available To Possible Worlds

Available Worlds

"Of all possible worlds [...], which is the best?" engineers ask when they try to solve a problem (H. A. Simon 1996, p.121).[15] Optimising all functions delivers the "utopia point", but since reality normally involves multiple demands, that optimum is usually "unattainable" (figure 1.16) (Arora 2012, p.665). Engineers use this process of optimisation to design a logical system to identify the available world closest to their aspiration (H. A. Simon 1996, p.117). Optimisation allows them to work within the world as it is, rather than imagine possible worlds that don't exist.

Designers face different demands from engineers, as they balance functionality and needs with desires. But designers also use optimisation, if tacitly, to solve the conflicting demands of a brief. However, even if designers quash their personal beliefs to provide a service, optimisation is not neutral; its variables, from cost to aesthetics, are weighted to the demands of the economic and political system that service-based design operates within. Optimisation has encouraged design to give form to the market's values, cementing design's function within it.

As a result, design has become a powerful tool to disseminate others' betters. For example, service design smoothes over neoliberal politics using tools like "captology", a process for making Silicon Valley's products "sticky" to generate value (Weisberg 2016).[16] Design can obscure problems, like enabling the "absolute obfuscation of labor and logistics behind a friendly buy button" in food delivery services (Sloan 2015). In 2010, the UK government adopted this "persuasive design" to modify citizens towards its idea of better behaviour by establishing the Behavioural Insights Team (2016) (AKA the Nudge Unit).[17] By giving form to, or masking, others' agendas, designers discreetly transfer power from consumers or workers to corporations or governments. A designer may not have control of the brief, but she carries responsibility in helping limit possible worlds by perpetuating the status quo.

Can changing optimisation's variables help us optimise for different possible worlds? Design is often championed as an "agent of change" (e.g. Rawsthorn 2013, p.27). But what change do we seek? In the past sixty years, design's critics have acknowledged that design isn't always progressive, doesn't always solve problems, and has made things worse (e.g. Packard 1957; 1960). Critics are also optimistic, suggesting ways to change. Victor Papanek (1972) argued for a more ecologically and socially responsible design. Ivan Illich (1973, p.84) critiqued Western capitalism and the rise of technocracy, observing that "Tools can rule men sooner than they expect; the plow makes man the lord of the garden but also the refugee from the dust bowl". He called for more "structurally convivial" tools like the telephone (1973, p.22). Lucius Burckhardt (1980) thought that classifying objects into types was the problem: neglecting their place in

15 His full question asks: "Of all possible worlds (those attainable for some admissible values of the action variables), which is the best (yields the highest value of the criteria function)?" (H. A. Simon 1996, p.121).

16 Captology was coined by the Stanford Persuasive Technology Lab (2017).

17 The unit is now a social purpose company. See Thaler (2009) for more on "nudge".

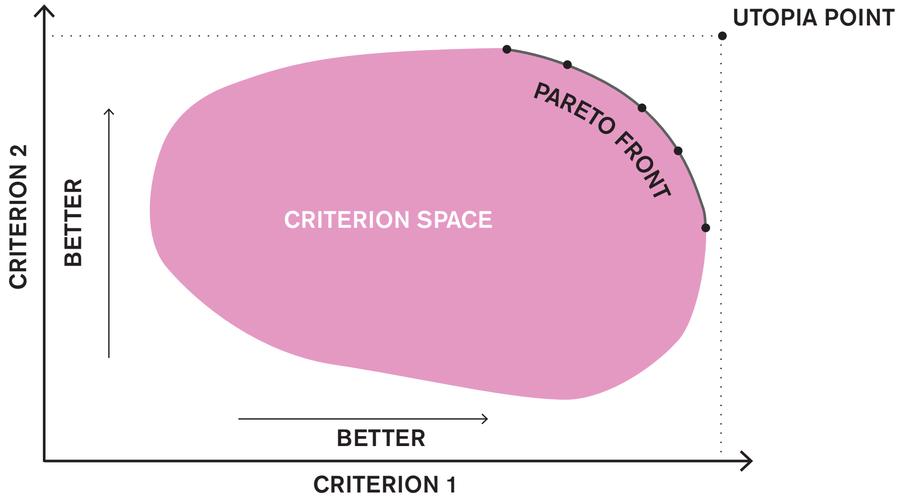

Figure 1.16
In optimisation design, the “utopia point”, the best design, is usually unattainable, since reality’s demands tend to conflict.

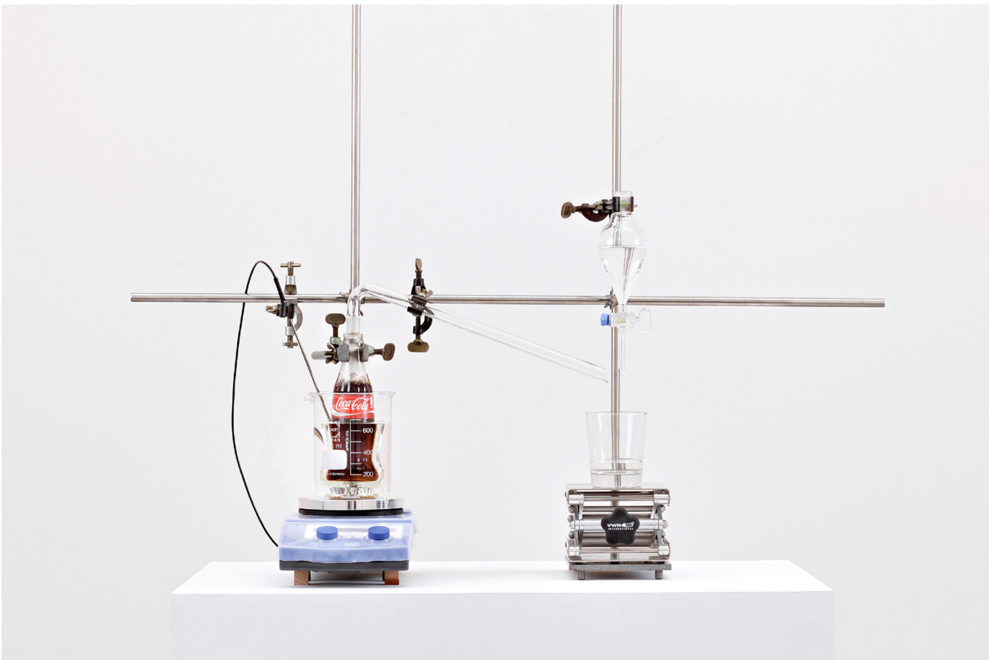

Figure 1.17
Helmut Smits’ reverse osmosis system “The Real Thing” (2006, realised 2014) purifies Coca-Cola into water (Widdershoven et al. 2014, p.25). Exhibited at “Sense Nonsense” (2014), the device reveals differences between art and design: The Real Thing may be ironic, but it is not useless. In some places, Coke is more readily available than water. Design cannot escape its optimism.

larger systems, we mistakenly better each in isolation. Ezio Manzini (2015) has suggested "co-designing" with users. Meanwhile, "transition design" theorists like Cameron Tonkinwise (2016a) place designers centre stage to help shift society to a sustainable future. It is easy to agree nominally with normative calls to design better, yet we still remain stuck in capitalism's paradox of limited resources and superabundance, fuelling it as designers and consumers.[18]

Designing against consumption is difficult when the logic of the system you work within demands it. "Green design" often fails because it must better conventional design by all measures, including cost. It tweaks parameters to make things a little better, without systemic change. Tonkinwise (2014a) has even suggested "undesigning". But does *not* designing solve design's problems? Optimisation encourages us to frame designers as problem solvers, like engineers. But then the plastic water bottle's failure could be blamed on the wrong question being asked: its design solves for strength, not disposability, ignoring context. Contrary to design theorist Richard Buchanan's (1992) advocacy of design thinking, perhaps "wicked problems" like sustainability or climate change aren't problems that can be solved by designers breaking them down into component parts for optimisation (Dunne & Raby 2014a, p.2). They are complex political and social issues. Politics, law, activism, philanthropy, and citizenship may be better tools to deliver a better world.

"Self Unself" (2013), "Sense Nonsense" (2014), and "Thing Nothing" (2015), three exhibitions at Eindhoven's Van Abbemuseum, rejected this mainstream imaginary of design as a technical process of optimisation and problem-solving (Schouwenberg 2014). Drawing on the reflective contemporary Dutch design tradition, the shows repositioned design as an aesthetic, irrational, poetic, and philosophical medium.[19] The works displayed were often critical, but by classifying the exhibits as design, the curators retained design's optimism in the face of its obvious failure to make a better world (figure 1.17).[20]

The idea that designers *should* solve the world's problems is less problematic than the belief that they could: designers have contributed to the global crisis caused by material culture by serving its industries; reshaping that culture requires societal change at the level of imaginaries, which determine the things we design. Design may express politics, but this thesis argues that it is not itself a political agent for change, as Fry (2011, pp.6-7) or Tonkinwise suggest, but a useful tool. Change is possible, and it is made possible because as an imagined thing, a social imaginary can be imagined to change, suggests sociologist Craig Calhoun (2016). Design can intervene by imagining possible worlds beyond the available, as critical design has.

18 Peter Frase sets out this paradox in *Four Futures* (2016).

19 This attitude emerged in the late 1980s, led by groups like Droog Design (Ramakers et al. 1998). For more on Dutch design for debate, see Simon Thomas (2008, pp.183-236).

20 My collaborative work the *E. chromi Scatalog* (see Chapter 5) appeared in "Sense Nonsense" in 2014.

Possible Worlds

Contemporary critical design has its roots in the "anti-design" or Radical Design practice of the 1960s, when in a period of declining technological optimism some architects and designers saw design's complicity in a destructive consumer culture.[21] Founded in 1966, Italian Radical Design practice Superstudio believed in architecture as a progressive force, but unlike contemporaneous techno-utopian groups such as Britain's Archigram, who imagined architecture as a rational industrial machine, they were critical of architecture's methods and its assault on nature. Superstudio began to dematerialise their designs (figure 1.18):

> In the beginning, we designed objects for production, designs to be turned into wood and steel, glass and brick, or plastic....
> Then we produced neutral and usable designs, then, finally, negative utopias, forewarning images of the horrors which architecture was laying in store for us, with its scientific methods for the perpetuation of existing models.... (Superstudio et al. 1973, p.17).

Superstudio's members even considered abandoning design for politics, where they thought real change could be effected (Ponti 1969). Radical Design was subsumed into consumerist design in the 1980s, but the Radicals' work contributed to Postmodernism's splintering of the Modernist doctrine, and promoted design for enquiry, not just problem-solving.

Drawing on the critical tradition, designer Anthony Dunne (1997) developed "critical design" with Fiona Raby to speculate how design's products could be imagined otherwise. They see critical design in opposition to "affirmative design: design that reinforces the status quo" (figure 1.19) (Dunne & Raby 2016). Design "must not just visualise a 'better world' but arouse in the public the desire for one" (Dunne 1997, p.74). Critical design acknowledges that things *could* be otherwise. But since all design seeks change for the better, clarifying "better" is crucial to differentiate critical design from mainstream practice. Dunne (1997, p.2) co-opted the established language of industrial design to seek new aesthetic and poetic possibilities, responding to the discipline's position within consumption. Rendering critical designs as products challenged the dominant dream of better from within, "turning design on itself rather than turning away from it" (Dunne 2016).[22] Artist duo Cohen Van Balen demonstrate this approach in *75 Watt* (2013), a product designed only to elicit choreographed movements from those assembling it (figure 1.20).

Critical design often exists in galleries or in academia, where designers have more agency.[23] Outside the market, designs can be used to extract ideas and serve us as people or citizens rather than just consumers. Even commercial designs can trigger debate with a change of context. The Victoria and Albert Museum's Rapid Response Collecting curators identify politically charged products in the news, which they provocatively add to the museum's permanent collection, like cheap trousers sewn in the collapsed Rana Plaza sweatshop complex in Dhaka, Bangladesh (Wainwright 2014).

21 For more on Radical Design, see Ambasz (1972) and Branzi (1984), Coles (2013) and Blauvelt (2015).

22 For more on critical design approaches see Mazé and Redstrom (2007), Pierce (2015), and Malpass (2016).

23 Disciplines like Human-computer Interaction (HCI) have also adopted its techniques (e.g. Sengers et al. 2005; J. Bardzell & S. Bardzell 2013).

Image redacted for copyright reasons
Available at: https://www.moma.org/collection/works/936?artist_id=8224&locale=en&sov_referrer=artist

Figure 1.18
Superstudio's *The Continuous Monument* (1969), a negative utopia, marks the group's transition from material experiments towards societal dematerialisation.

(a)	(b)
affirmative	critical
problem solving	problem finding
design as process	design as medium
provides answers	asks questions
in the service of shareholders	in the service of society
for how the world is	for how the world could be
science fiction	social fiction
futures	alternative worlds
fictional functions	functional fictions
change the world to suit us	change the us to suit the world
narratives of production	narratives of consumption
anti-art	applied art
research for design	research through design
applications	implications
design for production	design for debate
fun	satire
concept design	conceptual design
consumer	citizen
makes us buy	makes us think
innovation	provocation
ergonomics	rhetoric
user-friendliness	ethics

Figure 1.19
Dunne and Raby's manifesto *a/b* (2009) delineates differences in attitude between "affirmative" and critical design.

Image redacted for copyright reasons
Available at: http://www.cohenvanbalen.com/wp-content/uploads/2013/10/75Watt-4.jpg

Figure 1.20
Cohen Van Balen's *75 Watt* (2013) depicts the choreographed manufacture of an object designed only to elicit dance-like movement from its workers, intended as commentary on the logic of mass production.

In the RCA's Design Interactions (2014) department, Dunne and Raby developed critical design as a tool to explore the "social, cultural and ethical consequences of emerging technologies". We were taught to imagine other worlds through the objects that might inhabit them.[24] These worlds were often located in the future, using time as a narrative device to extrapolate and question an emerging technology (figure 1.21). Design is used "as a means of speculating how things could be" to "open up new perspectives" (Dunne & Raby 2014a, p.2). The priority is "story making" over "storytelling" (2014a, p.88), with the aim of "collectively redefining our relationship to reality" (2014a, p.2). For designer James Auger these speculative, critical designs (a subcategory since labelled by design studies scholars as speculative critical design, or SCD) can debunk the progress myth by showing us alternative futures. Rather than hoping for "a better version of better" to come our way, they let the audience scrutinise which is better now, identifying issues and opportunities in the process (see Rosell 2015).

Speculative design can be a critical technique; it is also used to explore, predict or promote technological futures for commercial purposes, helping to make possible worlds become available ones. Even prototypes can be classified as speculative designs—for mass production. Deeper into possibility space, designer Julian Bleecker (2009) advocates "making things to tell stories": what he calls "design fiction"; science fiction writer Bruce Sterling (2013) classifies these as "diegetic prototypes" that immerse us in narratives.[25] The electronics company Philips (2015) used this approach in their Design Probes to scope out provocative futures five to fifteen years away, like their "Microbial Home" concept kitchen (figure 1.22). Since imagining futures can make them more likely, commercial design fictions can help pull reality in their direction.

While the aims of commercial speculations are clear, a few commentators have argued that speculative critical designs, in contrast, lack normativity: they don't state what is better (e.g. Tonkinwise 2016b).[26] These works are often designed to encourage the audience to consider their own views, rather than prescribe the designer's. But a project can identify that the world could be otherwise without dictating *how it* ought to be. Presenting the possibility of alternatives, the designer can give agency to individuals to enact change. Dystopias like artist Atelier Van Lieshout's (2008) richly detailed *SlaveCity* (figure 1.23) function like this. Skewering optimisation, the imaginary zero-energy city is a concentration camp: dreams of a better future for all are impossible. We need to find other ways for the world to be.

Some critics have argued that SCD's practitioners, concerns (e.g. futures and emerging technologies), and consumers (e.g. gallery audiences) are blinkered by privilege, a critique summarised by design researcher Ramia Mazé's (2016) comment: "Critical for whom? By

24 For more on critical design using speculative techniques see Dunne and Raby (2014a), Auger (2012; 2013), and DiSalvo (2009).

25 Sterling borrows the term "diegetic prototypes" coined by film and science scholar David Kirby (2010, p.195) to describe "cinematic depictions of future technologies".

26 Ambiguity, thoughtfully deployed, can be more appropriate than didacticism if a work's function is to question or engage with philosophical ideas, or the fictions that are imaginaries. Some critics see a lack of commitment to a future, which reduces the possibility of critical opposition (e.g. Tonkinwise 2016b; see Pierce 2015, pp.41-2). But design need not be didactic; ambiguity should not be confused with a lack of critique of the status quo, nor a shirking of critique. Didacticism can exist elsewhere.

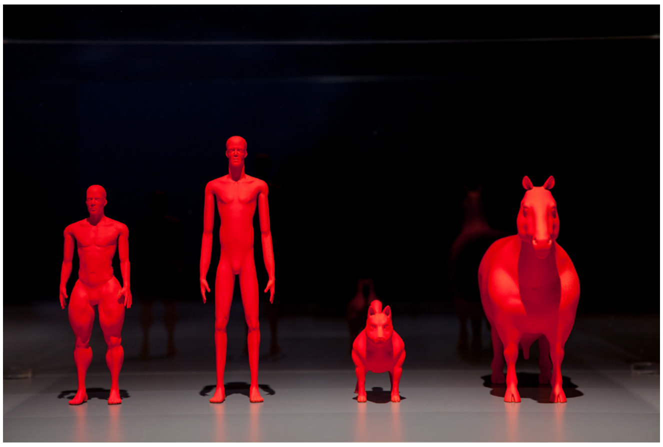

Figure 1.21
Speculative design can be used to explore the implications of emerging technology, as pioneered by Dunne and Raby. *United Micro Kingdoms* (2012-13) explores the effects of different ideologies on future subgroups. Here, “Anarcho-evolutionists” modify themselves and their animals.

Figure 1.22
“Microbial Home” (2011), a Philips Design Probe. The fiction is rendered through detailed props to imagine a kitchen of the future that uses biotechnological processes.

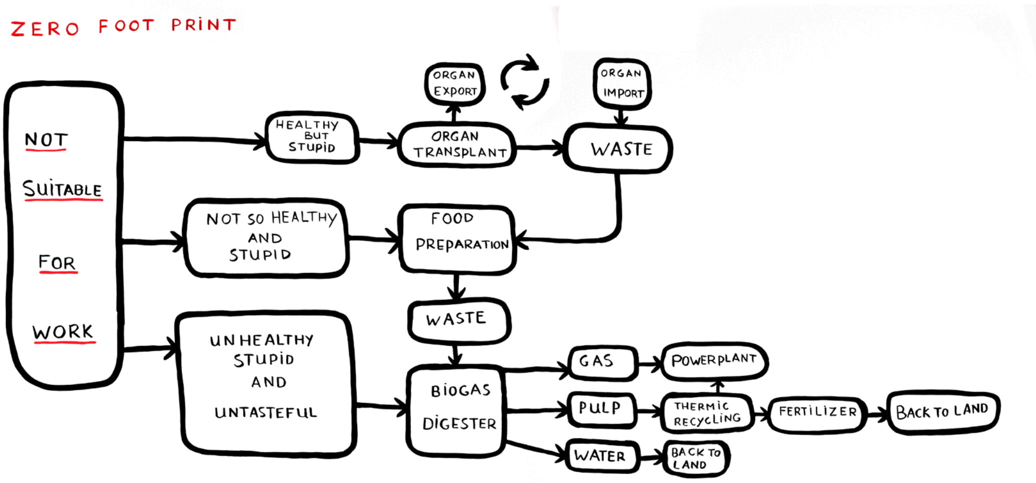

Figure 1.23
Diagram (2008) from Atelier Van Lieshout’s intricately rendered dystopia *SlaveCity* (2005-2009), which maximises efficiency from its inhabitants by recycling them: its circular system produces no waste, revealing the dangerous limits of optimisation.

whom?"[27] Certainly, critical design should seek out betters beyond those in elite venues like universities, where much work in this small, young field has been developed.[28] Diversifying practitioners and subject matter can generate new techniques in new contexts to open up possible worlds.[29] SCD has already introduced more women's voices into technology, including mine.[30] I am privileged to investigate emerging technologies and their imaginaries, which are often the work of the elite, but these are not elite concerns. The next chapters show how synthetic biology's visionaries, operating out of advanced technological societies, hope to impact on the world's richest *and* poorest, often determining for others the problems that need solving. We need ways to open up these processes for different audiences. To fully understand these powerful imaginaries demands active participation in a range of spaces, including elite ones. Shifting focus from the implications of technologies to the ideologies and imaginaries that shape their creation can broaden the work and its impact. But democratisation needn't exclude dedicated cultural spaces of contemplation like the gallery.

Fiction isn't the only tool to imagine possible worlds. Carl DiSalvo (2010; 2012) calls for a politically engaged "agonistic" or "adversarial" design, an attitude that resonates with my work's trouble-finding and troublemaking. He describes designs that embody politics through the democratic principle of contention, like Natalie Jeremijenko's (2017) ongoing "Environmental Health Clinic", which highlights environmental injustice and prescribes action. DiSalvo (2014, p.97) also advocates participatory design techniques in which reuniting the user and designer results "in more democratic conditions and outcomes" of making products. This "critical making" process materialises the political qualities of an issue "onto and through artefacts", rendering them a "collaborative and public endeavour of articulation" (2014, p.97). Other worlds can become possible through the construction of technical artefacts. His collaborative project "Drones for Foraging" (2014) detects ripe fruit trees in urban areas and alerts participants, forging a different way of existing in the urban environment. But DiSalvo argues that critical and speculative designs are not radical enough in their imaginings, lacking normativity. Yet the world imagined by his foraging drone is not radically different; it uses existing commercial technologies to tweak the present, operating within its parameters. Dictating that designers can only work on *what is* or *what needs to be*, rather than asking *what could be* limits the possibility of change.[31] Rather than restrict ourselves to the world already available, we can reimagine the world.

27 John Thackara's (2013) post on the MoMA *Design and Violence* blog sparked a strong debate between critics and practitioners. For a summary of this critique, see Pierce (2015). The core critics are a group comprising Ansari (2015), Kiem (2014), Oliveira (2014), Prado (2014), and Tonkinwise (2014b).

28 Any university course is elitist, and is increasingly so. Until recently UK university education was relatively affordable, especially compared to the US. When I completed my MA in 2009, the RCA covered fees and offered bursaries for most UK students; a two-year MA now costs £19,000 and £56,800 for UK/EU and overseas students respectively.

29 For the exhibition "Speculative Needs" at Beirut Design Week 2017, designer Tatiana Toutikian ran workshops at five Lebanese universities, both private and public, encouraging discussion around often unfamiliar bio and digital technologies through speculative design techniques (Aouf 2017).

30 Well-known female graduates of Design Interactions working on technology include Revital Cohen, Nelly Ben Hayoun, and Hiromi Ozaki (AKA Sputniko!).

31 Critical designers are not independent: what gets made and seen also depends on the tastes of curators, conference organisers, editors, commissioners, and the media. And non-commercial space and work is increasingly under financial pressure. Projects often begin in academic settings or as self-initiated practice, commissioned and funded by cultural institutions, similar to artworks (e.g. the Wellcome Trust, or museums, residencies or galleries). Some speculative design work is commissioned by thinktanks and policymakers.

1.5 Conclusions

Design, as the book *31 Brilliant Ideas FOR A BETTER WORLD* proclaims, makes better things that can better our lives. But that bettering is not absolute. It is contingent on contexts and people. Design is intrinsically optimistic, but different betters have shaped design and what we make with it. Twentieth-century designers in the West fuelled the fiction of the optimal design, weighting the levers of optimisation towards the dominant market paradigm and its economic betters. We can try pulling levers to produce more socially or ecologically aware designs, or we can challenge optimisation and the optimum, revealing the imaginary of better they prop up.

In doing so, critical design can explore what better means and its influence. Critical, optimistic design is constructive, seeking change, reminding us that the world could be otherwise. It aspires to a better future by arguing for—or against—it in the present. This chapter has revealed this internal conflict: an impulse to better the world, but without necessarily prescribing how the world should be. As design, it still can't help but dream of better.

Good critical design requires an understanding of the sociotechnical conditions in which it operates. This belief underpins the next three chapters. Moving on from design's dreams of better, I introduce my critical design work to analyse and explore synthetic biologists' visions of designing biology. They too are optimistic, dreaming that optimising biology will deliver the best of possible worlds.

Chapter 2. Better Biology

> "Making life better, one part at a time."
> —MIT Synthetic Biology Working Group motto
> (Campos 2012, p.118).[1]

2.1 Introduction

The message was diplomatic. "I would like to thank you for all of your service for Art and Design in iGEM last year. I think we got some good teams and the small exhibit we had could become the beginning of something great within the iGEM community", the email from the International Genetically Engineered Machine (iGEM) competition began. But despite the disagreements over the preceding months, I didn't expect what came next: "However in terms of the track and the award, we are moving in a different direction in 2015. We are making changes to the structure of the committee accordingly" (de Mora 2015). And with this delicate phrasing, I was released from my formal role in one of synthetic biology's key institutions.

I had been surprised eighteen months earlier in July 2013 when Randy Rettberg, iGEM's director, asked me to set up an Art and Design Track for its tenth annual meeting, or jamboree, in 2014. iGEM began as an undergraduate bioengineering competition at the Massachusetts Institute of Technology (MIT), inviting students to use the new synthetic biology methods to design organisms with "useful" functions. iGEM has been instrumental in embedding and globally extending synthetic biology's imaginary of an accessible, open-source technoscience: *biology made better*. As early as 2006, undergraduates were creating bacteria that were banana-scented (MIT iGEM 2006), or could detect arsenic (University of Edinburgh iGEM 2006). To realise their designs, students engineer BioBricks™—known sequences of DNA that are supposedly measurable, predictable, and controllable, like electronic components—then assemble them into biological "circuits", and insert them into bacteria or other organisms. These BioBricks are added to the open-source "Registry of Standard Biological Parts", its expanding collection distributed annually to the growing number of teams. In 2009, I inadvertently helped kick-start iGEM's art and design culture, working with designer James King as design advisor to the winning University of Cambridge team, who made pigment-producing bacteria (see Chapter 5).[2] Also in 2009, an arts team, ArtScienceBangalore, captivated iGEM with their bacteria designed to secrete the smell of monsoon rain.[3] Collaborations between engineering teams and artists and designers

1 The motto appears on each page of community website http://syntheticbiology.org. Austin Che, co-founder of Ginkgo Bioworks claims to have coined the phrase (Roosth & Che 2007).

2 Possibly the first iGEM interaction with artists/designers came from Imperial College London's iGEM 2008 team (2008), who were trying to control bacterial deposition of material to build a "BioFabricator". They consulted fashion designer Suzanne Lee, who was experimenting with growing bacterial cellulose into a sheet material.

3 The team were undergraduates from Srishti Institute of Art, Design and Technology, Bangalore

have since mushroomed, ranging from artistic enquiry to communication design.[4]

But in July 2013 I didn't understand why iGEM wanted to formalise this experimentation (see Appendix B). iGEM said they wanted to support the emergent art and design culture.[5] But what was this culture to them? Did they think it bettered synthetic biology? Did they want artists and designers to do synthetic biology, or to make work *about* it, exploring social or ethical issues? Did they want synthetic biologists to make art? Was it to engineer public acceptance? Artists and designers—including myself—have provided free publicity for iGEM and synthetic biology through our projects, talks, exhibitions, and events. Perhaps it was all of these: enhancing pedagogy, innovating techniques, broadening participation, exposing teams to alternative perspectives, encouraging critical enquiry, all whilst promulgating the imaginary that iGEM embodied of an open, easy-to-engineer biology.

I explained to Rettberg in July 2013 that segregating art and design into an application track, like "Energy" or "Health and Medicine", would eliminate the conditions that produced strong collaborative projects, and attracted outsiders like me in. I recommended a cross-track prize instead. I was told the track would go ahead, with or without me. At least I would see how an imaginary's values are codified into platforms, so I asked synthetic biologist Christina Agapakis to collaborate.[6] We pushed for the cross-track prize, but iGEM was adamant; in October 2014, however, they conceded a prize alongside the specialist track.[7] But over the next eighteen months, our better would clash with iGEM's. Our five track teams—one art/design, four engineering—were impoverished by a lack of collaboration, while interdisciplinary teams competing for the cross-track prize produced some fascinating work. The trouble certainly provided rich insight into working in and around sociotechnical imaginaries.

Since I became involved in synthetic biology in 2008, I began to notice what Agapakis (2014) calls its "collective fantasy", fuelling progress, hype, and resistance. What I now recognise as its imaginaries of better are examined in this and the next two chapters. My participation revealed that designing critically in synthetic biology means negotiating these powerful imaginaries. As my design work began to be absorbed into the field, I realised I was contributing to those imaginaries, even when my provocations were meant to challenge them. What was "critical" design here, and why do it? Was I hoping to *better* synthetic biology? To understand my interactions, and the nascent biodesign field they were encouraging (see Chapter 5), I needed

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(ArtScienceBangalore 2009).

4 Engineering teams have worked with artists and designers as advisors, collaborators or as team members. They have also done industrial design themselves, integrating wetware and hardware into prototypes. Art and design teams have worked with scientific advisors to produce biological designs, or alone, focusing on speculative designs (see Appendix B for examples). In 2010, I advised both the University of Cambridge and ArtScienceBangalore teams, and organised a Synthetic Aesthetics (2010) session at iGEM, where teams discussed emerging collaborations between synthetic biology, art, and design.

5 iGEM has accommodated other trends in the competition, adding a community laboratory (DIYbio) track, and including high school teams.

6 I first met Agapakis at iGEM 2009, when she was doing her PhD at Harvard University. By 2014, she had mentored iGEM teams at Harvard University and University of California at Los Angeles, and had been a Synthetic Aesthetics resident. For more on Agapakis, see Chapter 5.

7 Agapakis and I sent a 55-page proposal to iGEM in August 2013, documenting past practice to advocate for the prize, not track.

to understand synthetic biology's relationship with better. Why do synthetic biologists want to make better living things? What do they mean by better?[8] And whose better is determining our shared future? Informed by my interventions, Chapters 2 to 4 address these questions.

"Formulating a vision and constituting a group to advance it", STS scholar Steven Hilgartner (2015, p.35) explains, "is an imaginative act". Developing Jasanoff and Kim's sociotechnical imaginary concept (as described in the introduction), Hilgartner (2015, p.34) calls the individuals who imagine new possibilities, and the communities that they create to realise them, the imaginary's "sociotechnical vanguards". Vanguards develop the technoscience, lobby government agencies and industry to fund a speculative field, shape official visions, and drum up public support.

These three chapters centre on the dreams of vanguards in the US and the UK, who since 1999 have transformed a vision into a globalised technoscience. Using the sociotechnical imaginary's framework in my research—how ideas originate, are embedded and globally extended, and resistance to them—I saw that what better means, and who gets to decide, has proliferated in synthetic biology. Today, synthetic biology's imaginary as a whole dictates that we can and must better engineer biology, to better the world, and to better nature. However, this isn't one dream, but three. These chapters explore the different ideologies underpinning these betters. Synthetic biology's history is documented elsewhere, so rather than narrating the imaginaries' trajectory, I concentrate on ideologies, techniques, and critiques.[9] I watched these imaginaries develop first hand, and even participated in them: I use synthetic biologists' dreams of better to contextualise my critical designs, and, conversely, use my practice to show how it gains insights into, and troubles, the field's dreams of better.

I begin this chapter by introducing synthetic biology's engineering origins and how the visions were embedded. Describing resistance to engineering dreams, I then introduce my failed collaboration with the Warwick Integrative Synthetic Biology Centre (WISB), a new institution trying to establish a biology-led paradigm. Finally, I expand on my iGEM experience as I explore the conflicted extension of the vanguard's open-source vision.

Synthetic biology optimistically imposes the engineering mindset onto living matter to make biology better, trying to optimise biology to produce an optimum design. This embrace of design's bettering needs scrutiny. But critique is often poorly received. In 2009, anthropologist Paul Rabinow (2009, p.302) suggested that these claims of bettering needed attention:

> Synthetic biology's pioneers work hard at conveying a feeling of palpable excitement that biological engineering will invent and implement technologies that will make better living things, although exactly what that would mean beyond efficiency and instrumental capacity-building is largely unexamined.[10]

8 Claire Marris and Nikolas Rose (2012) have noted that better means different things to different people, that grand speculations limit real discussion, and argue for discussion of desirable futures.

9 For histories of synthetic biology, see Campos (2009; 2012; 2014).

10 Rabinow (2009, p.305; 2012, p.42) introduced to synthetic biologists the concept of "human flourishing", a metric of the good life. This translation from the classical Greek term *eudaimonia* continues to be referenced in the field: Endy's twitter bio for his handle @DrewEndy reads: "Let's enable humanity to flourish in partnership with nature."

Rabinow was in charge of the novel Human Practices Thrust at the Synthetic Biology Engineering Research Center (Synberc), the leading US research consortium.[11] But in 2010 he quit after a very public disagreement with Synberc's leaders about risk, collaboration, expectations, and ambition (Gollan 2011; Rabinow & G. Bennett 2012).[12] The widespread rejection of genetic engineering in the 1990s (especially in Europe) triggers a fear in synthetic biologists of an imaginary public who will refuse the technology (figure 2.1): what social scientist Claire Marris (2015) dubs "synbiophobia-phobia".[13]

Despite resistance to critique, social scientists' analysis (and that of a few bioethicists and historians of science) of the field touches on better.[14] This includes engineering's ameliorative processes (Mackenzie 2009; Calvert 2013b); governance and intellectual property (Bagley 2015); sustainability (Wiek et al. 2012), and the policy framework Responsible Research and Innovation (Hurlbut 2015a). They also look at value (Frow 2013), and vision making (Frow & Calvert 2013). Even the proposal for the Synthetic Aesthetics project, developed by bioengineers Drew Endy and Alistair Elfick, and social scientist Jane Calvert, was to "make synthetic biology better" (Ginsberg et al. 2014, p.282).[15] Since this research is often funded from scientists' research grants (as is some of my work), critique can jeopardise future projects, since synthetic biologists may

11 Synberc was funded by the National Science Foundation from 2006 to 2016. It included leading US universities, including MIT, Harvard, University of California, San Francisco, and University of California, Berkeley, as well as industry partners. The Human Practices Thrust was meant to be equal to the three science-based ones (Synberc 2016).

12 Rabinow described his concerns to *The New York Times* around biosafety and what he saw as a corresponding lack of concern from synthetic biologists (Gollan 2011). Jay Keasling, Synberc's director responded, citing failures in interdisciplinary interaction, accusing Rabinow's group of neglecting to produce communication materials for the public. After Rabinow left, Drew Endy took over Human Practices with scientist/engineer Megan Palmer, renaming it "Policy and Practices".

13 Some synthetic biologists shy away from discussing synthetic biology's potential risks, speculating only on its promise. Synthetic biology is shaped by many overlapping imaginaries, including "governable emergence", where science is the "engine of change", and law lags behind, potentially stymieing science's progress (Hurlbut 2015b, pp.128-9). Since the 1975 conference at Asilomar, US, on the regulation of recombinant DNA, genetic engineering has leaned towards expert self-regulation. At Asilomar, scientists agreed to self-impose restrictions on recombinant DNA technologies. Hurlbut describes how a faulty memory of Asilomar helps to reinforce an imaginary that casts technoscience as the driver of society, as novelty becomes the means to revolutionise society. We give agency to the experts—the scientific community—to select what is new and what thus needs scrutiny: "science acts, while society reacts" (Hurlbut 2015b, p.128). Scientists, not democratic institutions, lead governance; novelty becomes the public good, endangered by public anxiety. This imaginary is informed by the positivist belief that the scientific method is neutral, that science is motivated only by the good, its outcomes will only be used for good, and risks can be assessed. Even for a dual-use technology like synthetic biology, this scientistic culture dictates that scientists know what is better.

14 Most social science, policy, and bioethics work is themed around biosafety, bioerror (the technology going wrong), and bioterror (the technology being misused) (e.g. Palmer et al. 2015), governance and intellectual property, and moral issues (e.g. Nuffield Council on Bioethics 2016).

15 I first learned about synthetic biology from my RCA classmate Sascha Pohflepp. He had heard Drew Endy (2007b) talk at the Chaos Computer Club in Berlin in December 2007. I met Endy in August 2009 at Stanford University after asking to show him my synthetic biology related projects. I joined Endy et al. on Synthetic Aesthetics in February 2010, and helped to create a space for critique within synthetic biology. We concluded *Synthetic Aesthetics* by noting that "What is meant by 'better' is clearly the key question here. Does it mean technically better; that is, cheaper, faster, easier, and more predictable? Does it mean more useful or more profitable? More sympathetic to the nature of biological systems? More responsible or ethical? More sustainable, more beautiful, or more democratic?" (Ginsberg et al. 2014, p.282).

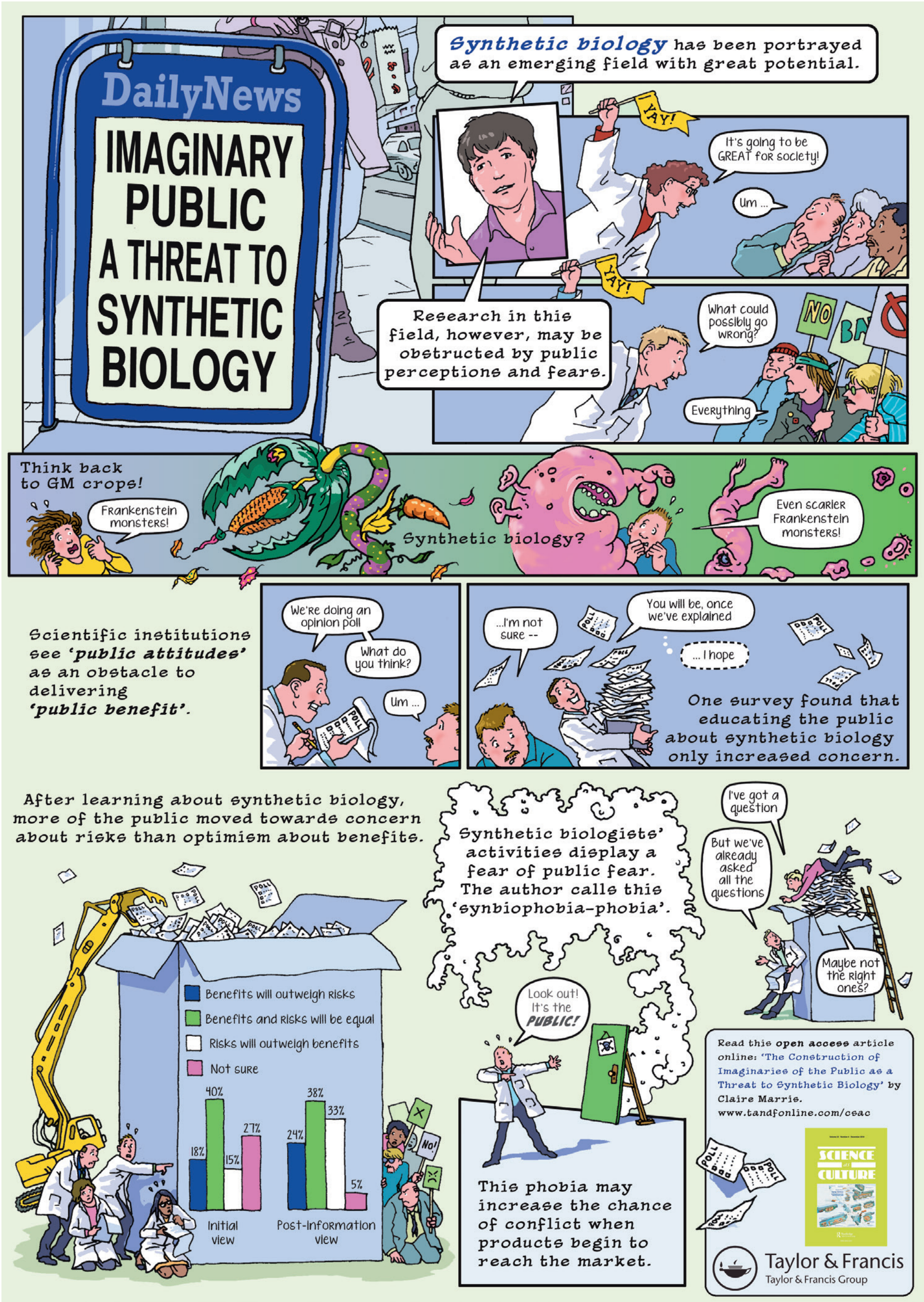


Figure 2.1
Social scientist Claire Marris (2015) has diagnosed synthetic biologists with "synbiophobia-phobia": the fear of an imagined public that fears the field.

refuse future collaboration.[16] Consequently, social scientists worry whether their work has demonstrably bettered synthetic biology (Calvert & Balmer 2009; Balmer et al. 2015; Balmer et al. 2016; Shapira et al. 2015). Similar concerns about synthetic biology's promises of better, and understanding my critical relationship to better, introduced in Chapter 1, underpin my investigation here.

We can't know whether synthetic biology will deliver a better future for all, some, or at all. But untangling how dreams of better are constructed and transmitted, by whom and to whose values, gives insight to motivations, identifies likely trajectories, and steps from them. STS scholars have begun this work. As synthetic biologists make new things, Jasanoff asks, who decides which are good? She calls for new ways to control "the process by which imaginative futures enter our lives" (OECD 2010). Calvert (2013b, p.417) concurs: "Since 'making life better' means different things to different people, the involvement of such new communities in synthetic biology could help expand and challenge dominant ways of imagining how we should make use of our increased powers to manipulate the biological world". Critical design and art practices can contribute here, suggest Calvert and Schyfter(2017). Building on the research of STS and others, this thesis argues for developing critical design techniques to analyse a technoscience, its design of visions, communities, institutions, and things, to identify spaces for critical intervention and to inform them.

2.2 Making Biology Better

Engineering Origins

To some extent, my difficulties with iGEM were down to the physical distance between us hampering communication, and the cultural distance between a well-funded engineering competition expecting an independent artist/designer to work for them for free. But it was also a stubbornness rooted in defending our respective visions of better. iGEM thought that adding art and design to the competition would make it better. But what was iGEM's better? Or, as I eventually understood: where did the reality I encountered diverge from the vision of better I *thought* I agreed to engage with?

The better I expected was the dream of a biotechnology that is easier to engineer and democratic; that imaginary, and its dizzying implications, is what first attracted me to explore synthetic biology. Drew Endy, a prominent and corralling force for synthetic biology, co-founder of iGEM and collaborator on Synthetic Aesthetics, helped to build that vision (Campos 2014). Introducing his ideology helps explicate my work, which responds to it.

When Endy looks at living organisms, he doesn't just see nature or sentient beings, or something useful. As he explained in a 2011 talk, titled "Building a New Biology", he sees a technology:

16 In the US and the UK, synthetic biologists' grants often include budget for social science research alongside the science, as a legacy of the Human Genome Project and its ethical, legal, and social implications (ELSI) component (see Chapter 5).

> Imagine that you like to build stuff, and you look at the living world as one of the most impressive technologies that's ever existed. It's already taken over the planet, it replicates, it's very tiny and it's very big, it makes all sorts of things. What if we could get really good at engineering biology, what would that look like?... So that's what this boy is asking. He decides to try (Endy 2011, p.424).

Endy pointed to the projector screen, where a cartoon boy wearing goggles and a tool belt was peering into a hot pool (figure 2.2). The boy is the hero of Endy et al.'s (2005) comic "Adventures in Synthetic Biology", published, fantastically, in the leading science journal *Nature*, alongside Endy's (2005) more formal manifesto, "Foundations for Engineering Biology". Reaching into the water, the boy grabs a bulging green creature and shouts to the female scientist looming behind him: "Imagine what might become possible if they were working for us!"

Is this simple dream of getting better at building stuff really what motivated the creation of a technoscience so powerful that it could alter nature? "These fantasies in a comic book are representative of desires, and the engineering community would like to make some of these fantasies come true", Endy (2011, p.424) told the audience. Endy was one of a small number of engineers and scientists in the US who, in the late 1990s, dreamt of "improving" on nature's "imperfect" ways. Better biology would better human life: "Biology itself is a natural resource that can be further adapted to help satisfy human needs", he wrote (2005, p.450). These men speculated that "real" engineers could engineer biology better than the biologists who called themselves genetic engineers (Campos 2009). To improve on what they saw as a badly designed system, they would build biology anew. Despite a failed experiment involving exploding organisms, Endy's cartoon ends with the boy's optimistic yell resonating from Earth: "But look at us, we're building stuff!"

After degrees in civil and environmental engineering, Endy had become fascinated by biology's constructive capabilities.[17] He and other engineers, physicists, and computer scientists were delving into molecular biology as technological developments, and the advent of systems biology in the 1990s suggested new opportunities (D. E. Cameron et al. 2014, p.382).[18] Endy (2008) wanted to know: "How do we make biology easy to engineer, so that anything we might want to manufacture out of the living world is something that we can pull off?".

This ameliorative impulse is integral to engineering, Calvert (2013b) observes in her study of synthetic biologists. If scientists seek to understand systems, engineers want to construct and control them. Engineers take a problem-solving attitude to meet a recognised need (Vincenti 1990, p.6).[19] For bio-artists Oron Catts and Ionat Zurr (2014, pp.27-37), this "engineering mindset" is troubling when applied to biological matter as engineers seek to control and manipulate life, turning it into a raw material. But the aspiration to better biology is not just instrumental. For some synthetic biologists—especially those with a biology background—constructing new biological things would let them "understand existing ones better" (Calvert

17 After receiving his PhD in biochemical engineering from Dartmouth College in 1998, Endy soon joined the private Molecular Sciences Institute in Berkeley, CA (see Campos 2014, p.333).

18 For more on this history, see García-Sancho (2012).

19 Calvert quotes Walter G. Vincenti's (1990, p.6) reference to British engineer G.F.C. Rogers (1983, p.51): "Engineering refers to the practice of organizing the design and construction of any artifice which transforms the physical world around us to meet some recognized need."

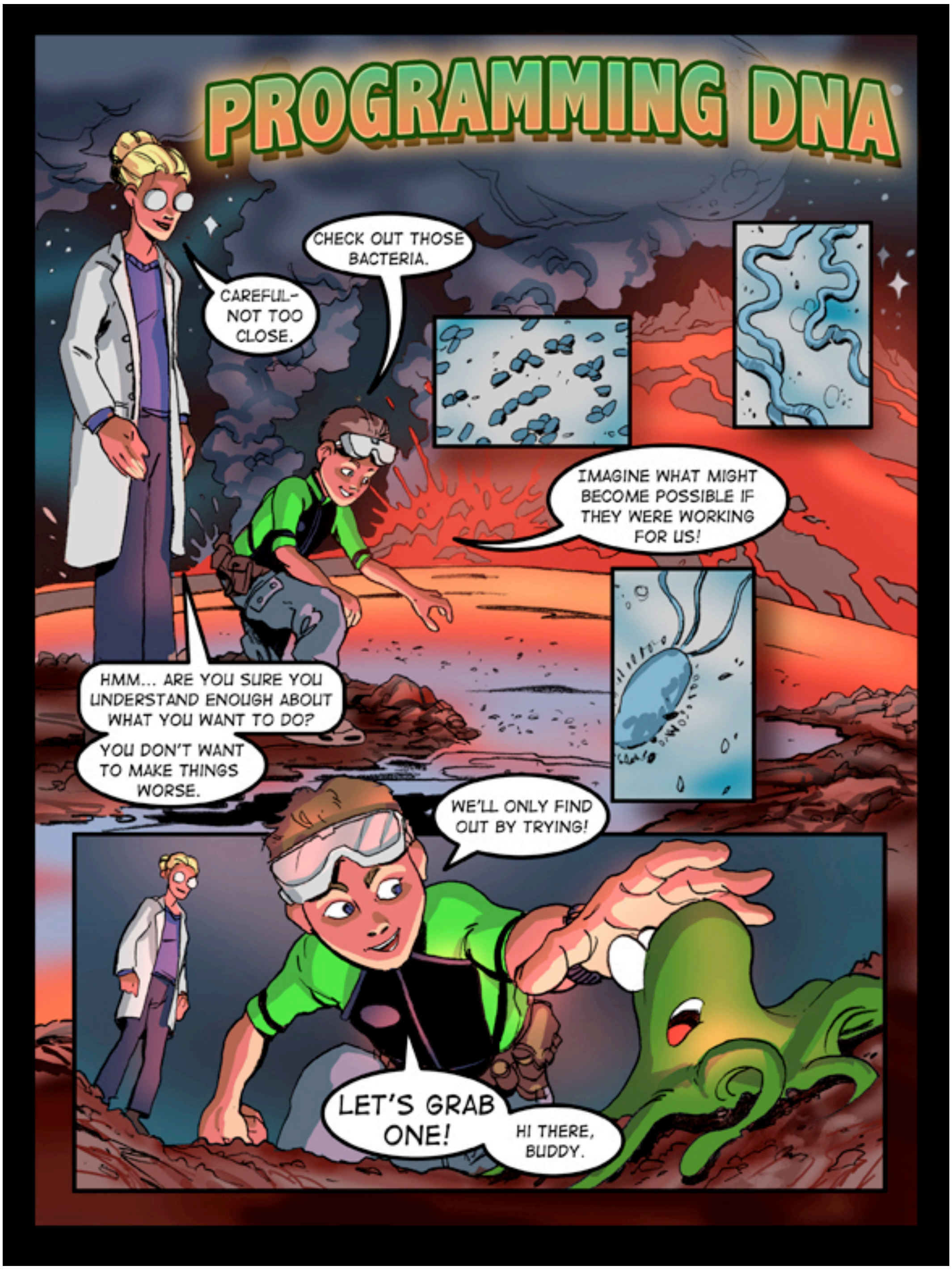


Figure 2.2
A comic accompanied Endy et al.'s (2005) manifesto for synthetic biology published in *Nature*. The opening page of "Adventures in Synthetic Biology" powerfully communicates the playful, can-do approach that Endy proposed.

2013b, p.409).[20] Still, this belief in the engineer's ability to control biology is fundamental to synthetic biology.

Using engineering concepts, Endy wanted to advance a much older idea that biology could be engineered, and that doing so would better our knowledge, and thus our lives (Campos 2009, p.6).[21] Recombinant DNA technologies have made editing biology at the genetic scale possible since the 1970s.[22] Earlier in the early twentieth century, the desire for understanding, inventing and owning nature was already evident in the patented works of Californian plant breeder Luther Burbank (J. S. Smith 2009, p.6). "For more than half a century I have had one definite object—the improvement of the vegetable kingdom for the benefit of man", Burbank (1923) proclaimed under the heading "Man Can 'Go Nature One Better'", posing with his strangely spineless cacti.

Synthetic biologists often validate their work by going even back further, referencing thousands of years of breeding. "The history of mankind is tantamount to the history of modifying nature to the benefit of human society", agreed Peter Schuster (2013, p.22), a theoretical chemist and expert in complexity and evolutionary mechanics, under the provocative title "Designing living matter. Can we do better than evolution?". The headline was also the name of a scientific meeting he helped to organise, where Schuster and others involved soon checked their hubris: "Do we really believe that we can do better than nature?" they asked, in apparent contrast to Burbank's macho certainty of a century before.

"Thinking more deeply, however, we realized that whether or not man can outperform evolution depends entirely on the interpretation of better", Schuster wrote (2013, p.21). If you optimise a single measure, design can outperform natural evolution. But nature, he argued, doesn't "optimise" single features in this way.[23] Evolutionary success depends on broader functionality and fertile offspring, while selection works at the scale of whole organisms in ecosystems. Bioengineers optimising for multiple criteria pull on individual levers, searching for the option that best fulfils a list of desires (2013, p.22).[24] But, as Chapter 1 showed, the optimum is a fiction, and better a subjective human value. Man can go one better than nature, but bettering traits is meaningless for an organism unless it helps reproduction. What is better for nature is oxymoronic, unless it improves survival.

20 For more on this idea of designing systems to understand them, see O'Malley (2009).

21 Campos reminded the field in 2007 that the term synthetic biology wasn't so novel: in 1912 Stéphane Leduc, a French professor of medicine coined *La Biologie Synthétique* (Campos 2009, p.8). Leduc (1912) conceived a "synthetic" approach to investigate the morphology of biology, emphasising the conceptual importance of synthesis for advancing knowledge. For further history of synthetic biology, see Porcar (2014).

22 Insulin has been manufactured by genetically modified yeast since 1978, while 70%-80% of packaged foods sold in the US contain genetically modified organisms (Gasparro & Bunge 2016).

23 Schuster is not a synthetic biologist: his article compares evolutionary or "irrational" design tools against rational design methods for "optimising" bacteria to make useful things for humans.

24 In optimisation design, this surface is called a Pareto line or surface. Vilfredo Pareto was an Italian economist who described a kind of "pseudo-optimality" where the results of different criteria are mapped against each other to find a best fit on a graphical 3D surface. For more on optimisation design, see Arora (2012).

For the engineering visionaries like Endy, a revolutionary, not evolutionary, technology was clearly better. Endy (2005, p.449) quickly concluded that evolution does not optimise its biological designs to make them easy for humans to understand or manipulate (see Campos 2014, p.334). Biology is complex: it does not function like the zeroes and ones of binary computer code. It is context-dependent—a single gene does not necessarily correspond to one function (an idea known as the "central dogma")—and its systems are "noisy", which improves adaptability. "Natural" biological systems are also full of imperfections, redundancies, and they evolve without intention (Agapakis 2011, p.9). Thus Endy proposed inventing simpler biological systems.

In 2002, Endy joined the computer scientist Tom Knight at MIT, where they established the Synthetic Biology Working Group (SBWG) with fellow internet and computer industry veteran Randy Rettberg (O. Morton 2005).[25] "It's time to rewrite the program", Knight would say of biological code (Goho 2003). They borrowed principles of abstraction from computer science ("black-boxing" a function's operating code to bypass detail), and standardisation from mechanical engineering (Endy 2005, p.450). "So each of these technologies—automation, standardization and abstraction—provides a platform for helping the process of engineering biology get better and better and better, and that's what synthetic biology is for me", Endy explained in 2008 (Lentzos et al. 2008, p.314). "Better" meant engineering and with it came engineering's optimism, its fiction of the optimum, and its processes of optimisation. This better would be embedded into the culture of synthetic biology and the things it made.[26]

The SBWG approach also drew on the concept of decoupling, which Endy (2005, p.451) described as the separation of linked systems or problems. Decoupling "allows some people to become experts as designers and other people to become experts as builders, like an architect and a contractor", explained Endy (2010, p.7). It also meant decoupling the design of biological parts (figure 2.3), like BioBricks, from their fabrication: biological information ("software") would be decoupled from material ("wetware") (Endy 2005; Calvert 2013b).[27] Some would design DNA, others would synthesise (print) it, all working to agreed standards within a community and its institutions, like iGEM.

iGEM proved a brilliant technique to extend the parts-based vision globally. It began as a short class at MIT in 2003 (O. Morton 2005), the same year that Knight (2003) published his standard for interchangeable BioBricks referencing Lego™ bricks (figure 2.4).[28] In 2004, Rettberg ran the class as a competition with five US university teams, going international in 2005 (J. Brown 2007).

25 Endy, Knight, and Rettberg set up the SBWG in 2002. Before stints at Sun Microsystems and Apple, Rettberg cut his teeth on ARPAnet, the precursor to the Internet, then working on the first TCIP/IP internet protocol (see Campos 2012).

26 International networks and institutions enabled by government agency funding were essential to growth. Synberc united institutions on the US east and west coasts; in the UK and Europe, funded networks helped to foster collaboration and community building before research centres were developed.

27 This connects to N. Katherine Hayle's (1999) critique of cybernetics and the disembodiment of information.

28 Adam Arkin and Endy (1999) wrote a white paper with for the Defense Advanced Projects Agency (DARPA), proposing standard biological parts. Too radical to receive funding, it still informed the work at MIT (Campos 2014, p.335). Endy et al.'s class was inspired by the revolutionary approach of Xerox computer architect Lynn Conway, who in 1978 got students designing circuits themselves (see O. Morton 2005).

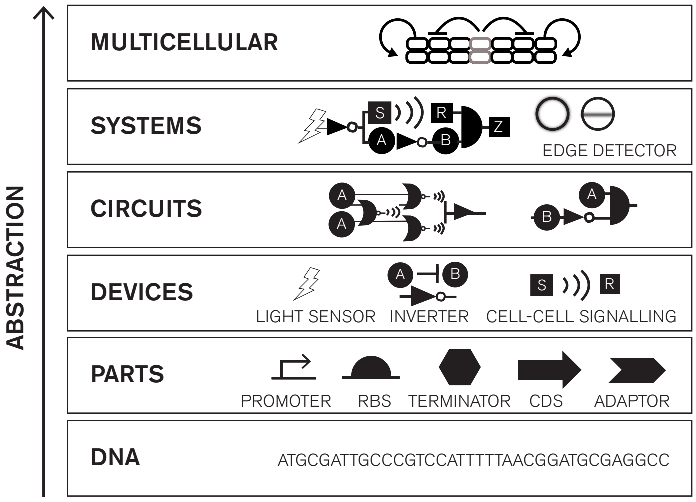
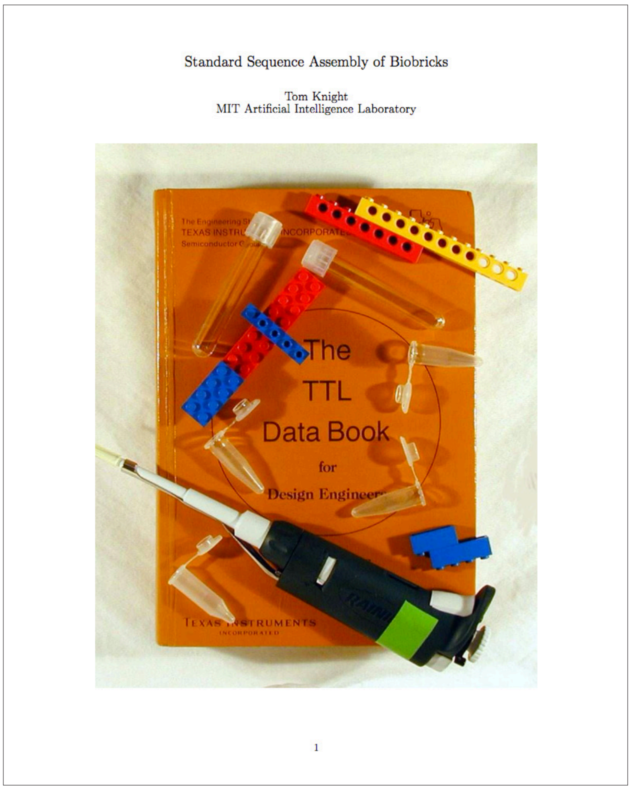


Figure 2.3
Synthetic biology's abstraction hierarchy superimposes a logical, engineering rationale onto biology. Increasing levels of abstraction from DNA into parts and then systems would allow the decoupling of information from biology, and the decoupling of expertise.


Standard Sequence Assembly of Biobricks

Tom Knight
MIT Artificial Intelligence Laboratory

1

Figure 2.4
The cover image of Tom Knight's (2003) "Standard Sequence Assembly of Biobricks", juxtaposing Lego™ bricks, pipette, and computing standards handbook, shows a promotion of playfulness and ease of assembly from synthetic biology's beginning.

In 2016, the jamboree involved 4432 participants in 300 teams from 42 countries (figure 2.5) (iGEM 2016).[29] iGEM introduces students, advisors, and their universities to synthetic biology, while their imagination, time, and money helps to stock the Registry of Standard Biological Parts.[30]

Figure 2.5
iGEM has grown from five teams in 2004 to 300 in 2016, when students travelled to the Boston jamboree from 42 countries.

Biological Resistance

Endy (2007a) also wanted to decouple biology from the "tyranny" of evolutionary constraints, described in his formula "Evolution = Tyranny". "We've got 3.6 billion years, approximately, of evolution, and it's beautiful and amazing. But if you gave me a cell and I looked at it, I wouldn't understand it—not at the molecular level; I wouldn't know how to use the DNA to design one myself. And so I wouldn't be able to say whether it was good or bad or ugly in its design," he admitted to the graphic designer Stefan Sagmeister (2006, p.101). Endy (2006, p.103) saw beauty in living things, but "As a biological designer, until I can actually design something, I don't understand it", he riffed on theoretical physicist Richard Feynman's chalkboard farewell.[31] Endy saw the opaque workings of some biological systems as evidence of nature's own efforts at decoupling "design" from function. His work was "implementing a collapse, basically, of the de-coupling". Human-designed decoupling would fix this gulf (2006, p.103). Good design meant code understandable by humans.

29 Compared to the biological sciences, synthetic biology is a tiny community. In 2004, Endy and fellow organisers expected 150 people to attend The First International Meeting on Synthetic Biology (AKA Synthetic Biology 1.0), but 500 applied, including press (the meeting was eventually smaller) (Campos 2009, p.18). iGEM's expansion, from 31 students in 2004 to 4432 attending (and 5600 participating) in 2016, clearly illustrates year-on-year growth. The Wilson Centre's "Synthetic Biology Project" (2013) mapped global growth in entities (companies, labs etc.) between 2009 and 2013, cataloguing 508 in total. Industry organisation SynBioBeta (2017) has begun tracking growth, noting $1bn invested in 2016.

30 The Registry is a digital library and a physical freezer. By 2016, it had 20,000 open-source parts. iGEM HQ ships each team a physical selection of parts, making good on its "give some and get some" ethos (iGEM 2016).

31 Richard Feynman (1988) scribbled on his Caltech blackboard "What I cannot create, I do not understand". This has become a mantra for synthetic biologists, with J. Craig Venter inserting this phrase into his "synthetic" organism (Gibson et al. 2010), although Caltech later admonished them for misquoting it (Ewalt 2011).

The engineering vanguard had to believe that biology's "natural" emergent and complex processes could be made predictable and designable. To conceptualise this control, they had to believe that they could separate or decouple biology from nature's processes and its context (Frow 2013). This requires belief in the very idea of "nature", a human construct.[32] For the growing community, biology was "a technology platform" (Platoni 2009), or a "technology" (Carlson 2010). While life was a useful, emergent property, it was "enchanted... from an experiential perspective" (Endy & Sagmeister 2006, p.103), but it was also a "kludge", a clumsy, improvised system that works (*The Economist* 2006).[33] This desire to rupture from the natural was clear in early definitions, such as "the intentional design of artificial biological systems".[34] "We're going from looking at the living world as only coming from nature, to a subset of the living world being produced by engineers who design and build hopefully useful living artefacts according to our specifications", Endy (2006) proclaimed. Better biology meant biology decoupled from nature itself. This better is authoritarian: biology is matter to be controlled by humans, decontextualised from its environment and its biopolitics.

Biology proved to be more complex and context-dependent than the engineers imagined (Kwok 2010; D. E. Cameron et al. 2014). The central dogma is not the whole story of genetics (Serrano 2007, p.2).[35] And what a biological part is turned out not to be so simple, as Campos (2012) explains in his history of the BioBrick and its troubled ontological, empirical, and legal status. Even "tyrannical" evolution is a useful design tool: humans can design constraints for biology to "find" its own solutions within; the difficulty with "directed evolution" is then preventing movement from the "optimum" design (see Cobb et al. 2013; Zakeri & P. A. Carr 2015).

Some synthetic biologists are questioning whether synthetic biology should develop a biological paradigm rather than forcing biology into the existing engineering one, allowing biology to evolve, adapt, or work in communities of different species. In my PhD practice, I interacted with one such group. In April 2013, biologist Orkun Soyer invited me to develop an artist's residency at the proposed Warwick Integrative Synthetic Biology Centre (WISB) at Warwick University. I would work with the centre on its vision to develop novel biological engineering approaches through projects such as evolvable circuitry (see Appendix C).[36]

32 I use the terms "biology" and "life" interchangeably in this chapter, as synthetic biologists do. Biology can refer to a scientific discipline, to biological materials and systems, and thus life. The Synthetic Aesthetics project involved much discussion about whether synthetic biologists were designing nature, biology, or life (see Ginsberg et al. 2014, p.272). Endy and Elfick saw their work as designing biology, while the social scientists and myself viewed it as designing life or nature. We eventually subtitled our *Synthetic Aesthetics* book *Investigating Synthetic Biology's Designs on Nature*.

33 "As an engineer, he can recognise a kludge when he sees one. And life, in his opinion, is a kludge", *The Economist* (2006) wrote of Endy in an early report on synthetic biology. Philosopher of biology Maureen O'Malley (2009) suggests that synthetic biologists resorted to the kludge as a design tool, not the clean, rational engineering design that they promoted.

34 For this and other early definitions of synthetic biology, see the Synthetic Biology Project (2008).

35 Endy would try to make parts that adhered to the central dogma (a project he named "C-Dog") (BIOFAB 2013).

36 As part of the UK's strategic efforts to develop synthetic biology, SynbiCITE at Imperial College London received £10m from the UK Research Councils in 2013, plus £14m from industry (C. Smith 2013). WISB was one of six additional UK Synthetic Biology Research Centres (SBRCs) that would be funded. In 2014, the universities of Cambridge, Nottingham, and Bristol shared more than £40m from the Biotechnology and

Soyer (2013a) saw potential for the artist or designer to add creativity and unexpected ideas, anticipating that I could "engage with our science both by contributing to its development and getting inspiration from it". The WISB funding bid, submitted in the summer of 2013, proposed to "bring art and design perspectives into the development of next generation SB [synthetic biology] and exploit these perspectives to actively engage with the general public" (Soyer 2013b). Fascinated by their envisioned biological paradigm, I planned to explore emergence, perhaps collaborating with Warwick's film or creative writing programmes. But my lab visits to WISB surprised me. Learning about the scientists' research didn't spark a reaction in me like the engineer's radical visions did; I realised trouble itself inspired my work. Soyer's biological paradigm was a "resistant" imaginary to the engineering one.[37] I didn't want to critique their provocation, since I sympathised with countering engineering's control. That left me simply to illustrate their alternative imaginary. As a critical designer, advocating a particular better felt odd.

Still, there was trouble to be had. Professor John McCarthy, WISB's director, wanted me to illustrate genetic engineering's purported benefits. For him, genetic modification could help to solve societal problems. Unlike Soyer, he saw my role as artist/designer-in-residence primarily in communicating that belief to the public. As at iGEM, diverging expectations about critical design were building that would make and usefully reveal trouble. WISB's 2013 research council funding bid failed, but in their successful grant application in late 2014, I was named in a proposed five-year, part-time academic role that led with supervising WISB's public engagement. I had originally pitched two options in 2013: doing communication work at commercial rates to fund independent research, or developing a more academic research post, which I thought was agreed. Leading with engagement may have been necessary to support the role through science funding, but I was increasingly worried that, if offered this post, I would be expected to promote their imaginary, not just explore its content. After 18 months of discussion and seven days of site visits, I withdrew from the project. The politics of progressing WISB's resistant imaginary had got in the way of our research collaboration. I needed to find ways to protect my critical work from synthetic biology's desire for acceptance, while still accessing its troubles, which I examine in Chapters 5 and 6. The experience explicated synthetic biologists' awareness of their vision making. It also showed how critical design is understood differently, even within synthetic biology. Whether WISB's resistant biological imaginary will prove better than the engineering imaginary is yet to be seen.

Better Open

Vanguards validate their visions by connecting them to established imaginaries, suggests Hilgartner (2015). For visionary synthetic biologists like Endy and Knight, computer science provided inspirational metaphors as well as counter-cultural possibilities. For the digital

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Biological Sciences Research Council (BBSRC) and the Engineering and Physical Sciences Research Council (EPSRC). In 2015, Edinburgh, Manchester, and Warwick shared £32m, with Warwick receiving £14m (BBSRC 2014a; 2014b).

37 For more on resistant imaginaries, see Jasanoff (2015b, p.332). For more on Soyer's evolutionary approach, see O'Mallley et al. (2015) and Calcott et al. (2015).

utopians of 1990s California like Stewart Brand, computers were no longer emblems of Cold War oppression but tools for personal liberation. The internet would enable a decentralised, collaborative society; the counterculture would finally be realised as a cybernetic society (Turner 2006). Inspired by open-source programming languages, Endy believed that DNA parts should be freely available, and patents—and thus value—should only apply to designed assemblies of parts (Campos 2012; Frow 2013). "Open-source biology" was even proposed as a name (Campos 2012, p.116).[38] For Endy, this "imaginary of openness" was better than the "dystopia of excessive privatization" (Hilgartner 2015, p.43).

This utopian democratisation was itself a resistant imaginary to industrial biotechnology. Endy saw "biotechnology 1.0" as industry-dominated, with innovation stymied by patenting regimes (Endy & Elfick 2014). The biotechnology industry had tried to improve its tarnished public image in the 1990s in Europe and the US with advertising that replaced fear with solving humanity's needs. "At the core of selling the life sciences is the desire to modify nature to better fulfil the dreams of human kind—to make a promise of a better future", notes social scientist Iina Hellsten (2002). But public resistance was also about ownership. In his fantastical 2007 manifesto, "Our biotech future", physicist and mathematician Freeman Dyson argued that "It is likely that genetic engineering will remain unpopular and controversial so long as it remains a centralized activity in the hands of large corporations."

The vanguard was building institutions like iGEM while encouraging a "biohacker" movement. "The hacker culture of playfulness has a great deal to teach biology", explained Roger Brent, director of the Molecular Sciences Institute where Endy worked in the 1990s (Hopkin 2004). Dyson (2007) agreed: "Domesticated biotechnology, once it gets into the hands of housewives and children, will give us an explosion of diversity of new living creatures, rather than the monoculture crops that the big corporations prefer." Synthetic biology brought engineers and scientists together, but Endy and others saw additional value outside: encouraging creativity and playfulness could better the world. This openness attracted outsiders, including me. A DIYbio subculture emerged with community labs like New York's Genspace. Its practitioners were welcomed into, and even came from, mainstream synthetic biology.[39]

Encoding these ideas of better—engineering, decoupling, openness, and creativity—into synthetic biology's structures has been key to its progress. "I think in practice, unfortunately, our experience has been, that if you don't construct dreams and cultures, that the practice will always relapse to the past or the status quo", Endy told me, explaining how he iterated iGEM rules, like making sharing compulsory, in response to teams' emergent behaviours. "It is essential to imagine alternate futures and paths for realising them, and to implement mechanisms or nudges that promote getting there, eventually" (2016, Appendix H, p.254).[40]

38 Other names suggested include "constructive" or "intentional" biology (see Campos 2009, p.18; Carlson 2006).

39 Inspired by MIT's famous hacker culture, and stories like the Homebrew Computer Club that spawned Apple, biohacking was formalised in 2008 as DIYbio, a global network of do-it-yourself enthusiasts and "garage" laboratories (Campos 2014). For more on biohacking in synthetic biology, see Delgado (2013).

40 At the first iGEM competitions, some participants would present their work, but refuse to share their parts, Endy told me.

Working with Endy on Synthetic Aesthetics from 2010 to 2014, I had some experience of this world-building potential. We had funding to run six paired residencies between synthetic biologists and artists/designers around the world.[41] They would spend two weeks in the lab and then the studio, visited by the social scientists and me. When the project was funded in 2009, Endy, Elfick, and Calvert, unfamiliar with art and design practice, had not allocated budget for making artefacts: the project was ephemeral (in four years, the twenty people involved, across five continents, never met together). As Design Fellow, I found that the more I told people around the world that a "space" for critique in synthetic biology existed, the more it became so. Over several years we built a global network, got residents' projects commissioned for other exhibitions, wrote a book, ran events, and inspired other projects. We materialised a space from a story.

I hoped that devising the iGEM Art and Design Track and Prize would similarly reveal more about the iterative, purposeful design of imaginaries, and provide a chance to shape work to my vision of better. From October 2013, Agapakis and I developed rules and requirements, medal criteria, and a judging rubric, assembled a committee and wrote a wiki primer on bio-art and biodesign, based on our vision of collaborative, critical work (see Appendix B). But reviewing our draft criteria, Rettberg suggested that "collaboration" was a weak term. Iterating iGEM with Endy, he explained he learnt that "helping" another team proved a better way to create a community (Rettberg 2014). This was troubling: I thought I was "collaborating" with synthetic biologists, but synthetic biology teams preferred to identify as the stronger partner.

Those entering the Track and Prize had mixed experiences. iGEM asked us to solicit entries, but as I had warned, art and design schools balked at entering an expensive bioengineering competition when students could collaborate beneficially with well-funded engineering teams.[42] The four engineering teams who picked our track made living artworks or tools to make art; the design team did no engineering (figures 2.6-8). Our expert judges described it as an exciting experiment that didn't work well. One branded two teams' work as, "in my estimation, clearly artless (i.e., not relevant to Art & Design)". By contrast, the cross-competition prize successfully encouraged engineering teams to work with artists and designers to explore applications and implications, with 31 of 240 teams entering. Their outcomes, including exhibitions, workshops, fictions, and prototypes, and BioBricks (figure 2.9-10) highlighted the isolation of the Art and Design Track. I was troubled by my involvement, as students and advisors had invested months in work that failed our rubric.[43] I offered to iterate the rules in my feedback to iGEM, but the fundamental issues were unavoidable. We were trying to craft an alternative dream of better in the shadow of iGEM's imaginary. Without iGEM investing in our better, it couldn't exist.

41 Synthetic Aesthetics was funded as a scientific research project by the US National Science Foundation (NSF) and the EPSRC, out of the 2009 synthetic biology "Sandpit" (see Ginsberg et al. 2014 p.xvii).

42 Art and design teams that can afford iGEM's price tag, especially without advance planning, are rare. iGEM can cost $50,000 for an engineering team, depending on team size and location. This includes team registration fee ($3500 in 2014, $4500 in 2016), teaching costs, laboratory reagents and consumables, DNA synthesis (sponsored in 2016), student summer stipends (if offered), regional meet-ups, additional events, team branding materials etc., jamboree attendance fees ($750 per person, $695 in 2016), and travel expenses to Boston.

43 Agapakis and I ran a feedback session at iGEM 2014 with participating teams and interested iGEM attendees.

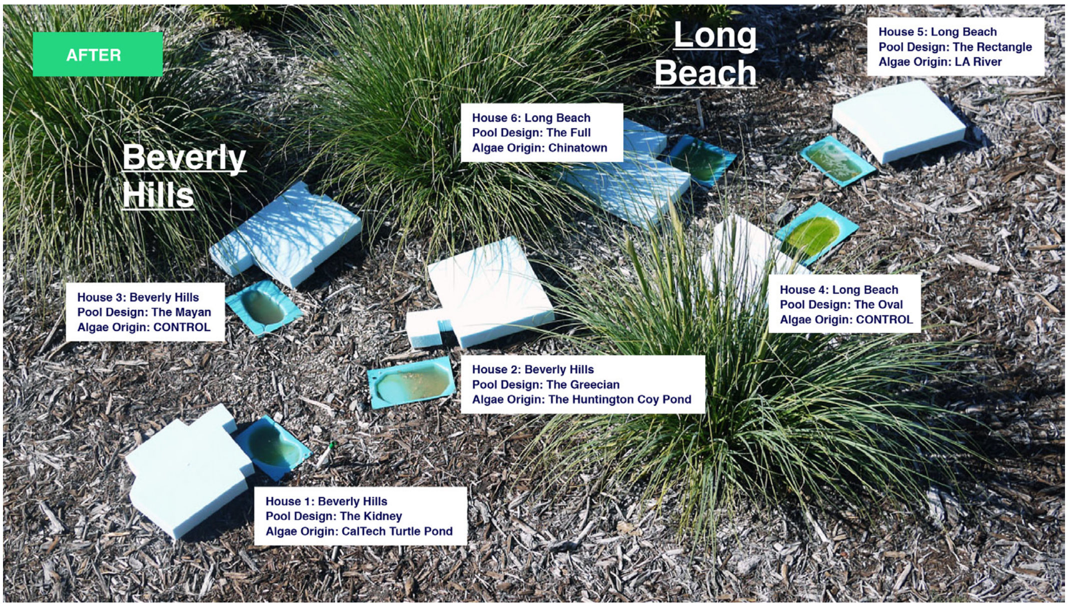

Figure 2.6
The ArtCenter MDP iGEM 2014 team's project *Car Pools* demonstrates how speculative projects can critically question synthetic biology. The art and design students did no bioengineering, but still probed questions around privately owned infrastructure and promises of algal ponds producing fuel.

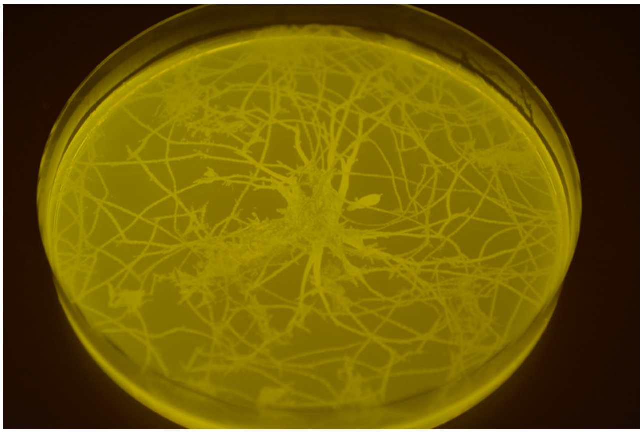

Figure 2.7
The KIT-Kyoto iGEM 2014 team comprising young engineering and science students presented a range of experiments for *E. motion*, their effort to express "emotion" though art. Here, their most interesting experiment, "Glowing Trails of Drosophila", shows "drawings" created by engineered fly larvae.

Figure 2.8
The Paris Saclay iGEM 2014 team was made up of scientists and engineers, whose art project *This is Not A Lemon* needing editing. The engineering of their synthetic "lemon" appeared underdeveloped.

Figure 2.9
The Paris Bettencourt iGEM 2014 team included two funded designers who worked in the lab throughout the summer. The resulting science project, *The Smell of Us*, addressing body odour with engineered bacteria, innovatively used provocative imagery to address body taboos.

Figure 2.10
The University of Sheffield iGEM 2014 team produced an industrial design prototype. Installed under a sink, their "Fatberglar" bioreactor would contain engineered bacteria that would release enzymes to degrade waste fat, preventing sewer "fatbergs".

Endy's vision for synthetic biology advocated decoupling so that experts from different disciplines across science and engineering would design biology together. iGEM thought they were being inclusive: artists and designers were now formally involved. But the new track segregated disciplines. iGEM saw value in art and design, yet disagreed on how it bettered synthetic biology: collaboration, not visualisation, has promulgated iGEM's image of inclusion and creativity. As at WISB, my understanding of design problematically diverged from iGEM's. For Agapakis and me, better meant scientists engaging with artists and designers to make more interesting, thoughtful, and creative bioengineering. Encouraging engineers and scientists to make art, dance their projects, or communicate better would not deliver that. iGEM's indifference towards collaboration limited their understanding of what we were fighting for, causing friction. They were promoting their imaginary through our interests, rather than engaging them.

iGEM's supposed openness masks an ongoing crisis within this dream of bettering biology. Endy continues to champion sharing at the level of parts through the BioBricks Foundation he founded in 2005.[44] Increasingly, though, this is the resistant imaginary to the dominant industrialised synthetic biology that emerges in Chapter 3.[45] Multiple parts libraries have appeared, some shared, others private, and often designed to incompatible standards (Frow 2013, p.439). Endy may have been inspired by Silicon Valley's digital utopians, but others preferred the patent protection regime and equity culture of its start-up scene (Hilgartner 2015, p.42). For them, intellectual property is seen as essential to justify capital to fuel growth.[46]

Hilgartner sees conflicting influences of openness and privatisation coming from computing culture, but Turner's story of 1960s hippie counterculture transformation into 1990s cyberculture shows that these cultures are not oppositional, but fundamentally linked. The

44 Endy had commercial interests as a co-founder of Codon Devices, which folded in 2009 (Campos 2012). His open-source efforts include the OpenWetWare wiki, and the SBx.0 conference series initiated in 2004, which helped to create a self-identifying community (D. E. Cameron et al. 2014, p.383), and SBOL (Synthetic Biology Open Language) a standardised visual and digital tool for representing genetic circuits, in development since 2009 (Galdzicki et al. 2014). Further institutionalising open source values, Endy's BioBricks Foundation (BBF) trademarked BioBrick™ and BioBricks™ in 2007 (Campos 2012). The BBF's (2011) mission was "to ensure that the engineering of biology is conducted in an open and ethical manner to benefit all people and the planet. We envision synthetic biology as a force for good in the world." Inspired by the Creative Commons simplified legal framework to promote sharing of copyrighted material, the BBF (2014) drew up the BioBrick™ Public Agreement (BPA), as "a free-to-use legal tool that allows individuals, companies, and institutions to make their standardised biological parts free for others to use". The contributor revokes intellectual property rights; the user promises to attribute the work. This would encourage innovation, and encode a moral good into the sharing of biological parts (see Campos 2012; Frow 2013; Hilgartner 2015). Endy and his collaborators defined better biology's moral code. But like the BBF, the BPA doesn't define the good life, leaving room for "incompatible visions" to be fought over (Hilgartner 2015, p.49). The BPA has not been taken up widely (Frow 2013), perhaps because of a preference for closed source, and technical problems with BioBricks.

45 Endy's design-and-build BIOFAB (International Open Facility Advancing Biotechnology) laboratory at Stanford University ran from 2010 to 2013 (BIOFAB 2016) to make professional-grade, well-characterised biological parts. It was a conceptual clash with the free-for-all of the iGEM registry, but sought to lure industrial partners to the parts-based approach (Campos 2012, p.135). Jim Haseloff of the University of Cambridge, the John Innes Centre, and the Sainsbury Laboratory in Norwich have set up OpenPlant (2016), a platform for open technologies for plant synthetic biology. It offers a legal framework to bypass IP issues, with input from the BBF's legal director, Linda Kahl.

46 These conflicting public and private intellectual property regimes have been discussed elsewhere (see Minssen et al. 2015; Rai & Boyle 2007; Peccoud 2016).

personal computer appeared to liberate us, but it also brought us under surveillance and closer to the market. Even synthetic biology's biohacker imaginary is mired in the Silicon Valley myth of entrepreneurs creating fortunes from their garages. The moral and economic paradox of openness and innovation that helped to spawn Silicon Valley—the "California ideology" (Barbrook & A. Cameron 1995)—is essential to the power of the dominant imaginary of better, seductively combining economic bettering with technological progress and aspirations to a moral good. This is as true for Silicon Valley as for synthetic biology and its dreams of better.

2.3 Conclusions

Synthetic biology's origins lie in its visionaries imagining that they could use engineering ideologies to update much older dreams of bettering nature. Better biology meant biology decoupled: by separating biology from its natural processes, diverse expertise could work together to optimise it. This better had an optimistic, moral dimension, as the vanguard borrowed ideas of democratic access to tools and technology from Silicon Valley's pioneers.

The vanguard designed standards, communities, and institutions like iGEM to embed and extend this dream of better. My troubled interactions with iGEM through the Art and Design Track and Prize provided deeper insight into how values are embedded into imaginaries, and extended globally. Working with others' imaginaries proved complicated. I discovered how hard it is to pursue alternative dreams from "inside" as an outsider, when others resisted what I thought to be better to meet their aims. At WISB, I found working on a resistant imaginary was complicated by the political ambition of those involved. Just as at iGEM, conflicting ideas of critical design's role clashed within an institution. Our differing understanding of what collaboration between synthetic biology and critical design offered hindered my participation, which I discuss in Chapter 5.

While this dream of an open, easy-to-engineer better biology was challenged by biology itself, and, as the next chapter shows, from industry, it still lingers in the cultural imaginary. The next chapters explore some of these conflicting dreams, and how my practice questions them.

Chapter 3. Better World

3.1 Introduction

“Is synthetic biology a disruptive technology that must promise to disrupt nothing?” asked Drew Endy (2014a). It was a good question, but I still objected. Endy raised the issue as he wrote to invite a journalist to chair our *Synthetic Aesthetics* authors’ panel. This would be one of twenty-plus events at our book launch in April 2014 at London’s Victoria and Albert Museum (V&A) where, against the backdrop of the world’s cultural heritage, we would transform the museum into a living laboratory for one evening (see Chapter 6).

I protested at Endy’s question because he had subtly rephrased a provocation that I had been making publicly since 2011, where I described synthetic biology as a promised “disruptive technology that also promises to disrupt nothing” (e.g. Ginsberg 2014a, p.41) (figure 3.1). I had noticed some visionary synthetic biologists promising that the new, better biology could build a better world. Their synthetic biology would simultaneously address the economy, the environment, and our desires, offering a better future of “sustainable abundance” that would maintain the status quo.

This chapter traces the emergence from 2006 of this second dream of better: a bioeconomy where oil, refineries, and synthetic chemistry would be replaced by sugar, engineered microbes, and the “green” technology of synthetic biology. By re-coupling industry with nature’s resources, we could “decouple” the environment from the economy, neutralising the incompatibility between sustainability and a capitalist system that requires 3% compound growth (see Harvey 2010, p.27).[1] Substituting the dead life in crude oil with living biology, synthetic biology would disrupt *how* we make things, not *who* makes those things, or *what* those things are. Change still meant operating within the system rather than imagining it could be otherwise, echoing my concerns with criticism of SCD in Chapter 1.

I thought Endy was repurposing my concerns as a guiding principle. He responded, explaining that synthetic biology was already clearly disruptive. He now spent more time with regulators than synthetic biology researchers, thanks to advances in DNA sequencing and synthesis. These were “disrupting security regimes that depend on physical isolation and also material supply chains.... So, I don’t have to promise to disrupt. I can point to actual documented disruptions” (Endy 2014b). Disruption meant change. But Endy was aware of his use of “must”:

1 There are two kinds of decoupling for industrial economies: “relative” (where natural resources usage rises more slowly than economic growth) or “absolute” (using fewer total resources); some advocate these strategies to “dematerialise” the economy (Goodall 2011). Decoupling is a contested route to sustainability as it still promotes growth (Jackson 2009, pp.47-58). And dematerialised products still require infrastructure: e.g. “cloud” computing needs energy-hungry server farms. Some also worry that current signs of decoupling may simply be artefacts of a badly designed accounting system (Wiedmann et al. 2015; Monbiot 2015a).

DISRUPTIVE WITHOUT DISRUPTING

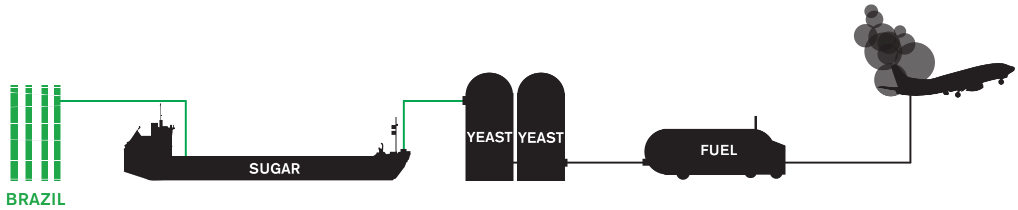

Figure 3.1
I used this image in my TEDGlobal 2011 talk, and in most talks since, to explain synthetic biology's promise of disruption without disrupting: sugar is transformed into jet fuel, so we don't have to change our behaviours.

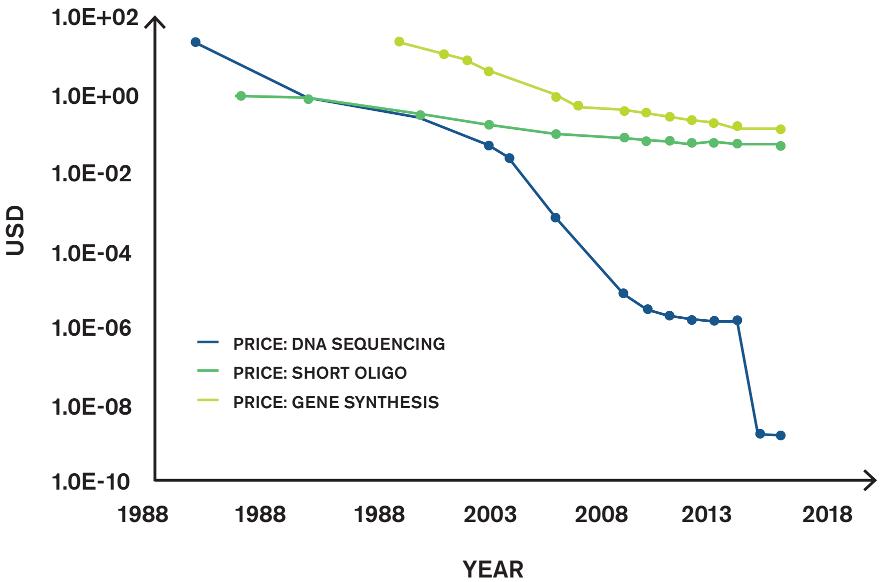

Figure 3.2
"Carlson Curves" drawn in March 2016 show falling prices per base of DNA sequencing and synthesis: two trends that have helped to fuel synthetic biology's progress as costs for iterating designs tumble.

> I prefer the word "must" because it more directly uncovers the question of who is making us promise? Are we making ourselves promise? If so are we self-aware of this? Or, are others making us promise? Or, something else? I [am] not fully satisfied with either form of the language here because it would seem that people (not technology) make promises; such human-made promises can be encoded or represented in technology and products. Is this right? (Endy 2014b).

Endy's invitation email identified two questions that he thought our book explored, the first about disruption, the second highlighting his own resistance: how could we "transcend" what he called "the mere industrialization of biology"? Recognising that synthetic biologists "must" promise to disrupt nothing, Endy suspected this would diminish synthetic biology's potential to better the world. Like me, he was observing the need for establishment buy-in, not advocating it. But what disruption meant to those invoking it, and why it was better, was still unclear. Silicon Valley's hardware, its software, and its dreams of better had inspired synthetic biology's vanguards. Now Silicon Valley's obsession with "disruptive innovation" was becoming a mantra. But disruption, as this chapter will show, is not a good in itself. Was it being used in synthetic biology just to mean change? If so, change from what, for whom?

This chapter focuses on ideas that have helped to embed and extend this second imaginary of better, and resistance to it. First, I introduce synthetic biology's influential vision of a bioeconomy, and then I examine the disruptive and solutionist mindsets that fuel it. Next, I discuss the resulting flawed imaginary of sustainable abundance, articulating how two of my projects, "Alternative Roads" and *Design Taxonomy* helped me to identify it. Finally, I examine the alternative betters revealed by NGOs and consumers that resist the obfuscation of reality's complexity to serve industrial dreams.

3.2 Sustainable Abundance

Bioeconomy is Better

"I've always been of the opinion that ethanol is for drinking, not driving," Jay Keasling, a biochemist and bioeconomy enthusiast quipped (Tollefson 2008). A leading figure in synthetic biology, Keasling has one foot in academia, directing the US Synthetic Biology Engineering Research Center (Synberc), and one in industry, with his company Amyris. For Keasling, it wasn't that biofuel was a bad idea, but that existing methods to produce it, and the fuels themselves, were inefficient. Synthetic biology could be used "to make better fuels—fuels with higher energy contents that are better suited to pipelines and other infrastucture [sic]" (Tollefson 2008). In "The promise of synthetic biology", Keasling (2006) proposed that "Rich, versatile biological systems are ideally suited to solving some of the world's most significant challenges, such as converting cheap, renewable resources into energy-rich molecules".

By 2007, the dream of sustainable abundance was fuelling a speculative sugar economy. Vats of engineered organisms would transform Brazilian sugar into more valuable commodities. "The reason to go to Brazil was pretty clear; it's the cheapest, most readily available source of sugar to power the technology platform," Keasling said (Regalado 2010). Under the headline "A better biofuel", the *MIT Technology Review* praised Amyris' efforts to make the high-energy fuel farnesene (Singer 2007). Two months later, their article "Building better biofuels" covered LS9, another Bay Area biofuel start-up co-founded in 2005 by George Church, a visionary Harvard synthetic biologist (Savage 2007). In the 1990s, first generation algae biofuel research had failed to deliver results, and was largely abandoned by investors in the US (Service 2011). Now major American corporations began to fund synthetic biology, with Exxon Mobil Corp. placing up to $600m into algae-based biofuels in 2009, including a partnership with Synthetic Genomics Inc., the company of genomics pioneer J. Craig Venter (Howell 2009).

Sustainable abundance was embedded in political visions. The Obama administration published its *National Bioeconomy Blueprint*, imagining a nation powered by biofuel and biorefineries (The White House 2012). For proof of principle, synthetic biology's supporters pointed to a feat of metabolic pathway engineering performed by Keasling and his team before they switched their focus to fuel. They had engineered yeast to secrete artemisinic acid, the precursor to the anti-malarial drug artemisinin (Ro et al. 2006).[2] With $42.6m funding from the Gates Foundation, this was not easy-to-engineer biology.[3] But in media and policy reports, artemisinin became emblematic of synthetic biology's potential, perhaps because it was the only visible product—most synthetic biologists were still working on foundational technologies—or because its (intentionally chosen) humanitarian benefits softened a widespread mistrust of genetic engineering.[4] Nature's vagaries and market forces would no longer interrupt the world's anti-malarial drug supply, currently sourced from sweet wormwood crops in China and Vietnam. Instead, better biology would produce an endless stream of the drug, grown in a vat, fed on monoculture sugar, and licensed royalty-free to the pharmaceutical company Sanofi.[5]

Coupling economic growth with biological growth has been a powerful concept in the neoliberal imagination. In their exploration of the human tissue market, Catherine Waldby and Robert Mitchell (2006) suggest that under capitalism, biological waste is transformed by its future promise.[6] The sustainable abundance vanguard promised that synthetic biology's organisms would transform waste biological matter into material with economic value, whether biomass left over from farming or fuel crops grown on what they often described as "marginal lands" (e.g. The White House 2012, p.20). Abundance would have no negative impact. Such fantasies are not unique to synthetic biology.[7]

2 More recent work in Paddon et al. (2013).

3 A further $20m appeared from Silicon Valley investors, like billionaire Vinod Khosla, co-founder of Sun Microsystems (Pontin 2007).

4 The positive coverage reaped Keasling *Discover Magazine's* Scientist of the Year accolade in 2006 (Zimmer 2006).

5 Amyris and University of California, Berkeley, licensed the technology (see Marris 2013).

6 "Biovalue is premised on what we might call 'speculative biology'; that is, biovalue refers not to the stable and known properties of tissues but to the capacity of tissues to lead to new and unexpected forms of value", explain Waldby and Mitchell (2006, p.108). For example, discarded, cancerous tissues proliferate into profitable cell lines (see Skloot 2009). Waldby and Mitchell (2006, p.84) describe waste—quoting anthropologist Mary Douglas's (1991, p.36) evocative characterisation of dirt as simply "matter out of place"—as a vital source of value for successful economies. For more on biocapital see Sunder Rajan (2006; 2012).

7 Nanotechnology was popularised by engineer K. Eric Drexler's (1986) visions of "molecular assemblers" that would be "engines of abundance" for humanity. His 2013 book's opening lines echo synthetic biology rhetoric: "Imagine what the world might be like if we were really good at making things—better things—cleanly, inexpensively, and on a global scale" and, "If we were that good at making things, the global prospect would be, not scarcity, but unprecedented abundance—radical, transformative, and sustainable abundance.

"One key endpoint of synthetic biology is industrialisation", Richard Kitney, a vanguard industrialist, regularly announced (e.g. Kitney & Freemont 2012). Kitney contributed to the UK's official *Synthetic Biology Roadmap* (UK SBRCG 2012), and its 2016 update, *Biodesign for the Bioeconomy*, which promises to "Maximise the capability of the innovation pipeline" and "Accelerate industrialisation and commercialisation" (SBLC 2016). The social and environmental benefits of the bioeconomy and its vats of microbial factories were promoted as irrefutable, neatly avoiding issues that tainted genetic engineering, such as economic monopoly and environmental release. Synthetic biology would disrupt industry, providing a flow of sustainable abundance, bettering all our lives.

Disruptive Influences

"I was called many things—audacious, arrogant, rebellious, and maverick—but the most flattering would have been disruptive", J. Craig Venter (2007) boasted in his prestigious Richard Dimbleby Lecture, referring to his race against the public effort to sequence the human genome. Venter, a geneticist and entrepreneur, is famous for founding Celera Genomics Inc. in 1998 and outpacing the Human Genome Project (HGP), running since 1990. Published in 2000, the draft human genome sequence was described as a shared victory (Human Genome Project 2000). Venter founded Synthetic Genomics Inc. in San Diego in 2005, and in 2006 established his not-for-profit J. Craig Venter Research Institute, a major contributor to synthetic biology's progress (e.g. Gibson et al. 2009).[8]

Directly quoting Wikipedia to explain disruptive innovation, Venter (2007) described "a technological innovation, product, or service that eventually overturns the existing dominant technology or status quo product in the market". Deploring what he saw as a lack of planning and science in combatting climate change, he told the audience, "We need new disruptive ideas and technologies to solve these critical global issues", adding: "I believe the best examples of disruptive technologies that could change our future are in the new fields of synthetic biology, synthetic genomics, and metabolic engineering."

Less than two years later, Synthetic Genomics (2013) had partnered with Exxon Mobil to develop biofuel. Although substituting products meant business as usual for industry and consumers, the "disruptive" label began to be applied to synthetic biology, perhaps inspired by Venter's (2007) dramatic declaration that a better future—and even "the future of life" itself—was possible

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We would be able to produce radically more of what people want and at a radically lower cost—in every sense of the word, both economic and environmental". Drexler's ideas have been described as "scientific speculation" based in "magical thinking", while in contrast to the synthetic biologists, Drexler "has never done laboratory work" (see Baum 2013). Yet these ideas are picked up by others: entrepreneur and scientist Peter Diamandis, a leading Silicon Valley techno-utopian seeking to accelerate progress through technology, is an abundance evangelist, advancing it through his institutions, the Singularity University and the X Prize Foundation. "Abundance for all is actually within our grasp", Diamandis (2012, p.9) proclaims in *Abundance: The Future is Better Than You Think*. For more on abundance rhetoric around new energy technologies, see Sovacool and Brossman (2013), and on nanotechnology's visions, see Milburn (2003).

8 Venter's maverick reputation is cultivated; he is even photographed sailing his yacht Sorcerer II around the world to scoop up microbes to sequence and patent. See *Life at the Speed of Light* (Venter 2013). Venter recently co-founded Human Longevity Inc. with abundance enthusiast Peter Diamandis, aiming to extend the human lifespan (Regalado 2015b).

only through the creation of synthetic life. Could we change the world while changing nothing? Clearly, someone or something was going to get disrupted, and the oil companies did not want to be amongst them. Disrupting the status quo was good as long as the disrupted were the disrupters. This vision of disruption extended globally, but was this disruptive innovation?[9]

The concept of disruptive innovation was invented by Harvard professor Clayton Christensen (1997) in *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*.[10] Christensen's theory has caveats. He saw established businesses focused on keeping customers happy by making "good products better" ("sustaining innovations"), meanwhile companies with simpler products or services enter at the bottom of the market, meet unmet needs, move upwards, and knock out the incumbents (Christensen et al. 2015). Cheaper, less functional, and with lower margins, disruptive innovations are often *worse* than the current offer. Christensen describes smaller disc drives with less capacity disrupting bigger storage formats as computer usage changed. Crucially, disruptive innovations often find new markets to disrupt, rather than new technologies.

Twenty years later, disruptive innovation is proselytised by Silicon Valley. Digital technology allows small teams to open up huge markets while avoiding material or labour costs traditionally associated with scaling up; these businesses are lauded for "disrupting" the status quo. The ride-hailing smartphone platform Uber disrupts taxi systems worldwide, without owning cars or employing a workforce (Morozov 2016).[11]

Synthetic biology's technological progress and potential low-cost reproducibility suggests parallels with Silicon Valley, inferring the latter's successes are replicable. Synthetic biology's own advance is linked to the falling cost and rising performance of DNA sequencing and synthesis (printing) technologies (figure 3.2), tracked by bioeconomist Robert Carlson (*The Economist* 2006).[12] Scientists can increasingly cheaply transmit DNA code electronically, synthesise it, and insert it into cells to make millions of copies.[13] But as a technoscience, not a product, synthetic biology itself is not a disruptive innovation. And disruptive innovations are meant to be cheaper, lower quality or simpler than those available. Industrial synthetic biology

9 For example, a 2009 *Nature* editorial pronounced: "The technology is disruptive, with the potential to transform biological engineering" (Unbottling the genes 2009).

10 Disruptive innovation relates to earlier ideas of "creative destruction", described by economist Joseph Schumpeter (1942) as the "incessant" process "essential" to capitalism, where the old is replaced by the new.

11 Start-ups own less material stuff. The photo-sharing application Instagram began with fifteen employees, and was sold to Facebook for $1bn after two years; by contrast the photography and film processing company Kodak once employed 145,300 people (Leslie 2014). Top-down, globalised platforms impact on local choice as they disrupt systems of welfare, taxation, and local oversight. Relentlessly user-centric and designed to be sticky, these platforms make it hard to act as good citizens. Morozov (2016) decries Uber's innovation model as funded by money that should otherwise be tax income; it goes against the commons, the common good, the commonwealth, and *actual* sharing. Sharing others' assets is the Silicon Valley interpretation of a sharing economy.

12 Carlson has been involved from the outset, meeting Endy at the MSI in the late 1990s (see Carlson 2010). His "Carlson Curves" mimic "Moore's Law," the observation in 1965 by Intel co-founder Gordon Moore that computing power doubled every 18 months.

13 A panel at the SynBioBeta Activate! China 2016 conference discussed "China's Challenging Reputation in the IP Arena" (Forbush 2016). Theft of microorganisms is apparently a real problem, since only a small sample is needed to brew copies.

has focused on producing copies of chemicals, promising that they are of equal quality so as not to disrupt. Development and regulation often makes them more expensive, which social scientists Joyce Tait and Geoffrey Banda (2016) identify as an obstacle to desired disruptive innovation.

Synthetic biology may produce disruptive innovations in the future, but the term was never intended to be a business strategy, it was a tool for managers looking to spot threats; even Christensen (2015) recognises its overuse.[14] Disruptive innovations are also not necessarily good, since they create by destroying others. We can disregard Christensen's theory, which has faced critique (e.g. Lepore 2014),[15] to consider disruption itself. Industry and policymakers now fetishise disruption—meaning change—as a marker of better products. Tait's (2016) exploration of governance strategies to promote both "incremental" and "disruptive" innovations in synthetic biology neither questions why disruption is better, nor describes the theory's origins.[16] As Endy pointed out in his email to me about the V&A event invitation, synthetic biology is disrupting supply chains and legislation, for better or worse. But in the Silicon Valley model embraced by synthetic biology, disruption's goodness is measured by financial success, not social or environmental well-being. So why is synthetic biology hailing *change* as the solution to make things better?

Solutionist Thinking

The dream of sustainable abundance, and its invocation of disruption without disrupting, has origins in the solutionist mindset. "Solutionism" is technology critic Evgeny Morozov's (2013) name for a form of technological utopianism where every social problem has a technological solution.[17] Solutionists, Morozov argues, risk focusing only on problems that have neat or technological solutions; some problems on closer investigation may actually be positive glitches in the system. Leaving no room for imperfection, ambiguity, or difference, he sees solutionism as reductionist of the human condition. Solutionism describes one vision of what is better: if it works in Palo Alto, it will be good everywhere (2013, p.8).[18] This solutionist approach is apparent

14 Christensen et al. (2015) argue that Uber is not technically disruptive, since it originally provided a *better* service for existing taxi users.

15 Historian Jill Lepore (2014) savaged Christensen's theory, questioning the case studies it is built on and its predictive ability. This sparked fierce protection of Christensen from his collaborators in the—perhaps self-interested "disruptive"—online business media, see Lambert (2014), Thurston (2014), Bennett (2014), and Gilbert (2014). In 2015, business professor Andrew King and graduate student Baljir Baatartogtokh (2015) endorsed Lepore's suspicion, showing that the theory remained largely untested in academic literature, and that many of Christensen's examples did not meet his own criteria. In *The Disruption Dilemma*, professor of strategic management Joshua Gans (2016, p.53) accepts the theory, but warns of its uncritical overuse from academics, those fearing disruption, and hopeful disruptors alike. If you can predict a disruptive event, then it is not really disruptive.

16 The value of disruptive innovation for synthetic biology is similarly endorsed in Wellhausen (2009).

17 Morozov (2013, pp.5-6) borrows the term "solutionism" from architecture and planning, where its derogative use describes "narrow-minded solutions".

18 *Soylent*, a meal-replacement powder invented in the San Francisco Bay Area, is an example of solutionist thinking. It is embraced by tech workers who don't want to waste time eating, but the company also has food aid in its sights (L. Russell 2013), even though global nutrition aid experts and activists advocate food, not food substitutes, as best practice (e.g. Danovich 2015).

in synthetic biology, as visionaries promise that their technoscience can solve some of the world's complex problems from the isolation of the laboratory, over social or political means.

Solutionism is connected to the technologically deterministic idea that technology makes things better. In her influential critique of disruptive innovation, historian Jill Lepore defines progress as "the history of human betterment". After the savagery of two World Wars, she argues that western societies substituted progress for the "new"; whether new was better was not dwelled upon (Lepore 2014). This innovation obsession influences Silicon Valley and synthetic biology too.[19] An image of a new, revolutionary technology benefits synthetic biology: "disruption" attracts academic funding and distinguishes it from genetic modification and its problematic image. For industry, presenting it as a technological "evolution" means it won't disrupt existing regulation.

Solutionism demands novelty, but new is not always better, cautions historian David Edgerton. And innovation does not necessarily lead to extended use or change. There is often a lag between invention—the creation of a new idea—and innovation, its first use. Many of the newest technologies incorporate functions of older ones, and an old feature can solve a new problem:

> Genetic engineering, and its positive and negative impacts, is discussed as if there had never been any other means of changing animals or plants, let alone other means of increasing food supply. A history of how things were done in the past, and of the way past futurology has worked, will undermine most contemporary claims to novelty (Edgerton 2006 p.xvi).

He observes that engineers have shifted from maintaining systems to emphasise "their role in innovation, design and creation of new things" (2006 p.100). But older inventions, like antibiotics or electricity, may still have more impact on our lives than newer ones, argues economist Robert Gordon (2016). For human-computer interaction experts Paul Dourish and Scott D. Mainwaring (2012), our focus on building the future "blinds us" from taking responsibility for what we have already made.[20] Similarly forward looking, synthetic biology's sustainable abundance vanguard pushes its technology as the solution, even if better alternatives exist.

If Lepore thinks that we have switched better for newer, Morozov (2013, p.x) sees the opposite in Silicon Valley, where "Innovate or Die!" has become "Ameliorate or Die". There, the idea that "Technology can makes us better—and technology will make us better" is endemic (2013, p.5). Silicon Valley's political leanings may influence this solutionism: supporting capitalism, many of its members see government as an "investor" in citizens, essential to enable them to give their best to society (Ferenstein 2015a).[21] For them, innovation is the goal of civil society; mechanisms that protect workers from capitalism are rejected. Citizens can solve their problems though competition and the market, a kind of communitarianism where "there is always a better solution that is great for nearly everyone". Innovation drives change, and 70% of Silicon Valley

19 Lepore (2014) suggests that innovation went mainstream after the 9/11 terrorist attack on New York City.

20 Quoted in Morozov (2013, p.1).

21 Silicon Valley is a cocktail of Republican, Democratic, and libertarian views, according to technology journalist Gregory Ferenstein (2015b). Although the technology elite overwhelmingly supported the Democrat party in the 2012 (and 2016) US presidential election, they view its institutions like healthcare as ripe for disruption (2015a).

believes that "change eventually makes things better, because society learns from its mistakes" (Ferenstein 2015a).[22] As synthetic biology draws on Silicon Valley's ideology and, increasingly, its investment (Check Hayden 2015), its values—using technological novelty and the market to determine what is better, not democratic or societal processes—will determine what gets designed using biology, and for whom.

Even the DIYbio movement and its open-source origins are being influenced by the Silicon Valley solutionist culture as community labs now incubate start-ups.[23] The market, disrupting existing systems, and innovation are the gauges of bettering. But technology alone won't make things better. Solutionism has allowed the promise of sustainable abundance to mask greater complexity. It becomes too easy dismiss scientific obstacles like whether the technology can solve the problem, or whether it is appropriate to. It also avoids ethical, biopolitical, and social issues, discussed next, including who benefits or loses out from its use.

The Imaginary of Sustainability

Imagining streets softly illuminated by the blue-green glow of genetically modified, bioluminescent trees (figure 3.3), the University of Cambridge iGEM 2010 team insisted to me that glowing trees—a constantly revived meme (see Chapter 5)—were sustainable, and their designs for extra-bright bioluminescent bacteria were a first step towards this future. As their design advisor, I ran a workshop to unpack their assertion of sustainability. Did they mean that these trees would reduce energy consumption, or that they would be socially sustainable by using open-source genetic material, or something else? The students couldn't understand my questioning of something that to them was so obviously sustainable. The glowing trees story went with them to the jamboree with *New Scientist* reporting that "Glowing trees could light up city streets" (Swain 2010).

If better means sustainability, what exactly does sustainability mean for more experienced synthetic biologists? Reviewing forty international reports on synthetic biology from 2004 to 2011, sustainability scientist Arnim Wiek and his co-authors found sustainability mentioned in twenty-one. Of these, they found most offered no definition. "What is perhaps most notable

22 "Silicon communitarians" can disrupt politics with their vast capital, shaping the world in their image. In 2015, Facebook founder and CEO Mark Zuckerberg and his wife Priscilla Chan publicly posted a letter to their newborn daughter, promising to give 99% of their Facebook shares (worth $45bn in 2015) to a new Chan Zuckerberg Initiative (CZI). They want the investment to be used to help her "grow up in a world better than ours today" (Zuckerberg 2015). The Chan Zuckerberg Biohub will invest $3bn into disease research (Kaiser 2017). Whether a tax vehicle or a true urge for bettering, a billionaire philanthropist cannot avoid but skew the world to their vision and politics. The HBO sitcom *Silicon Valley* satirises the "making the world a better place" reflex. The running gag, according to showrunner Mike Judge, was a response to Silicon Valley. He saw "capitalism shrouded in the fake hippie rhetoric of 'We're making the world a better place,' because it's uncool to just say 'Hey, we're crushing it and making money'" (Marantz 2016). Clay Tarver, a writer and producer on the show notes that "at the very least, we're making the world a better place by making these people stop saying they're making the world a better place" (Marantz 2016).

23 Biohackspace members have started companies producing things like cheap lab equipment, such as the Bento Lab—a compact kit including centrifuge and PCR thermocycler available for preorder for £999—funded via a Kickstarter campaign. The company PILI, producing "living ink", has emerged from the Parisian biohackspace La Paillasse.

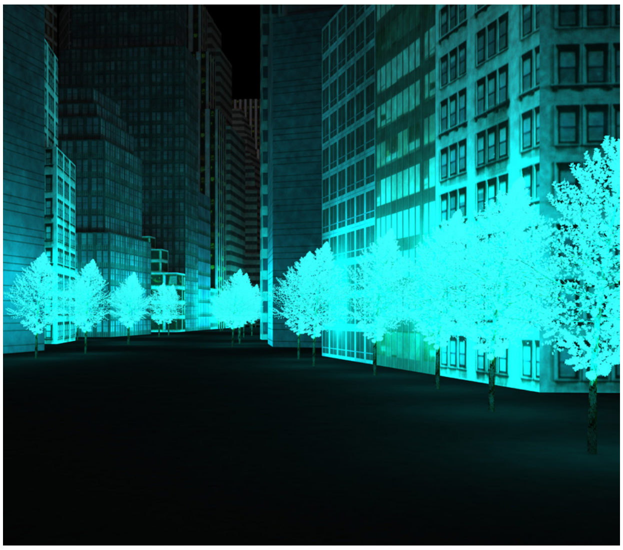


Figure 3.3
New Scientist used this speculative image to report on the engineering of super-bright glowing bacteria—*E. glowli*—by the University of Cambridge iGEM 2010 team (2010). Under "Future Applications", the team explain on their wiki that, "We created a 3D model to try to visualise a city lit by bioluminescent trees".

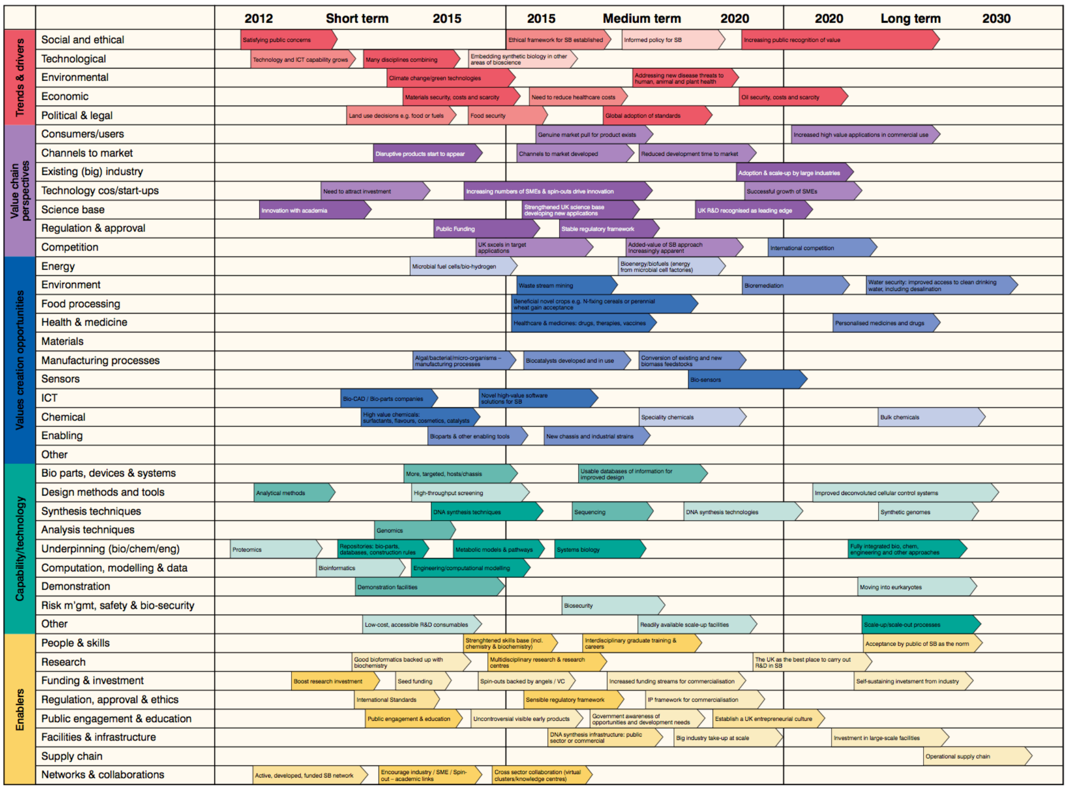


Figure 3.4
The UK government-sponsored synthetic biology *Roadmap Landscape* (UKSBRCG 2012).

about the discussion of sustainability in synthetic biology today is its absence", they write (Wiek et al. 2012). They call this synthetic biology's "imaginary of sustainability". Either funding agencies were expecting its mention, or synthetic biologists were offering it. In reality, sustainability is a broad concept, with simultaneous ecological, economic, and social dimensions.[24] Sustainable development describes efforts to meet present needs without impinging on future generations' (Brundtland 1987, p.16). How could synthetic biology become a sustainable technology if it was being developed in a context that ignored the detail?

In November 2013, I had the opportunity to investigate what I came to identify as this dream of sustainable abundance. *Dezeen*, a design news website with global readership, was curating an exhibition for the car brand MINI for the London Design Festival in September 2014. *Dezeen* invited me to join five other designers exploring the future of mobility, asking me to connect this theme to synthetic biology. Instead of promoting the existing substitution of materials—biofuels powering combustion engines, or tyres composed of non-biodegradable rubbers, derived from sugar not oil[25]—I wanted to explore how synthetic biologists envision sustainable alternatives: energy sources, materials, supply chains, and manufacturing processes, to identify opportunities for intervention (see also Chapter 5 and Appendix D). My research revealed that while sustainability and disruption were being used to embed and extend synthetic biology's imaginary of world bettering, they lacked definition.

The UK's *Synthetic Biology Roadmap* (figure 3.4) leads with a vision of an economically sustainable synthetic biology (UK SBRCG 2012, p.7); environmental challenges are only mentioned later. Intrigued by the UK's prioritisation of economic sustainability, I proposed the MINI brief as an experimental case study to SynbiCITE co-directors Paul Freemont and Richard Kitney, vanguards of the UK's industrial vision, and contributors to the *Roadmap*. Funded in July 2013, SynbiCITE, at Imperial College London, is the UK's leading synthetic biology research centre, housing research labs and start-up incubators to stimulate new industries.[26] From my initial research into mobility and synthetic biology, I developed an installation proposal for MINI. Based on this, I ran "Repair Ecologies", a one-day workshop for twelve SynbiCITE members. Exploring how synthetic biologists defined sustainability, disruption, and good biological design, I hoped to identify deviations between their individual ideas of better, the official vision, and the reality of their practice.

After talks at the workshop about sustainability, our discussion sessions confirmed a lack of resolution of its meaning, and how to realise it. Figure 3.5 shows the diverse values that participants suggested for a sustainable synthetic biology, from "adaptive" to "permanence". These overlapped with "disruptive" values for best practice, which themselves drew on biological

24 Wiek et al. define sustainability using six principles, including (1) maintaining the "viability and integrity of ecosystems" as an essential "valuable good in themselves"; (2) "human and social well-being"; and (3) "equitable opportunity for livelihood and economic activities". These must be (4) "enacted within communities", (5) "between interdependent communities" and (6) "over time" (2012). The authors suggest developing a model of *anticipatory governance* and normative, transformative sustainability science: see Guston (2008).

25 Tyre manufacturer Michelin is working with Amyris (2016) to develop renewable isoprene.

26 Kitney promised that the centre would "break down road blocks so that new industries can be developed, which could ultimately help to safeguard the UK's economic future" (C. Smith 2013).

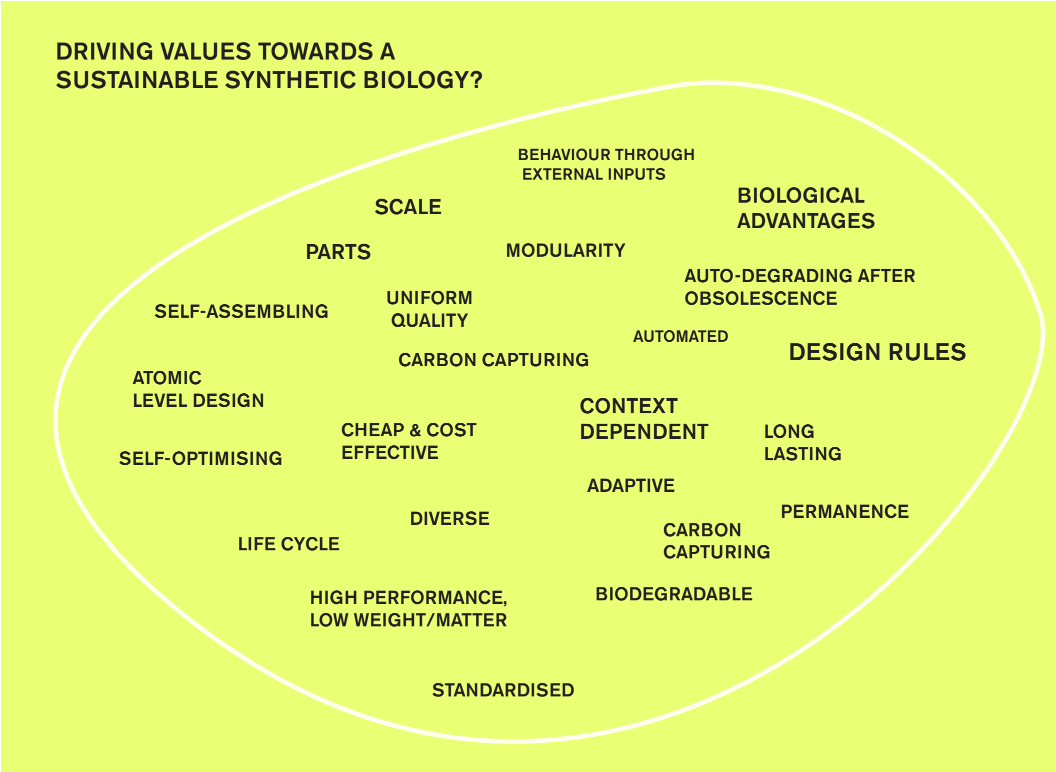


Figure 3.5
Workshop participants saw values ranging from “adaptive” to “biodegradable” as definitive of a sustainable synthetic biology at the “Repair Ecologies” workshop (2014).

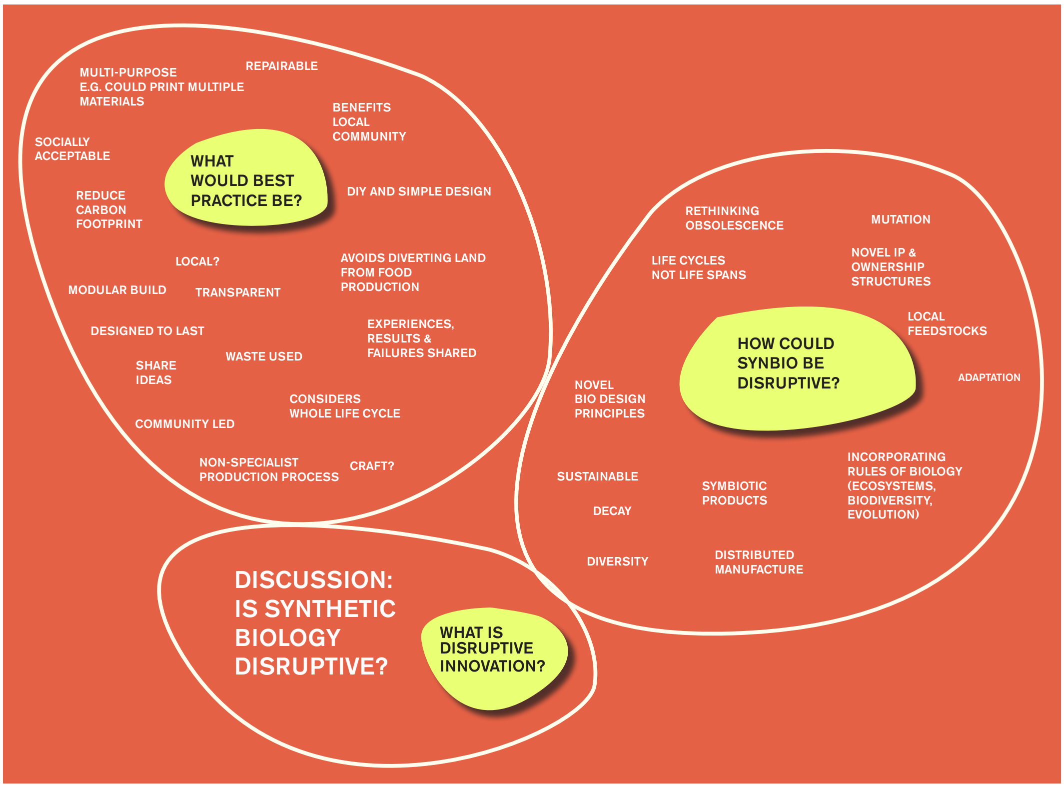


Figure 3.6
Participants defined “disruptive” synthetic biology as ranging from “community led” to including “symbiotic” products.

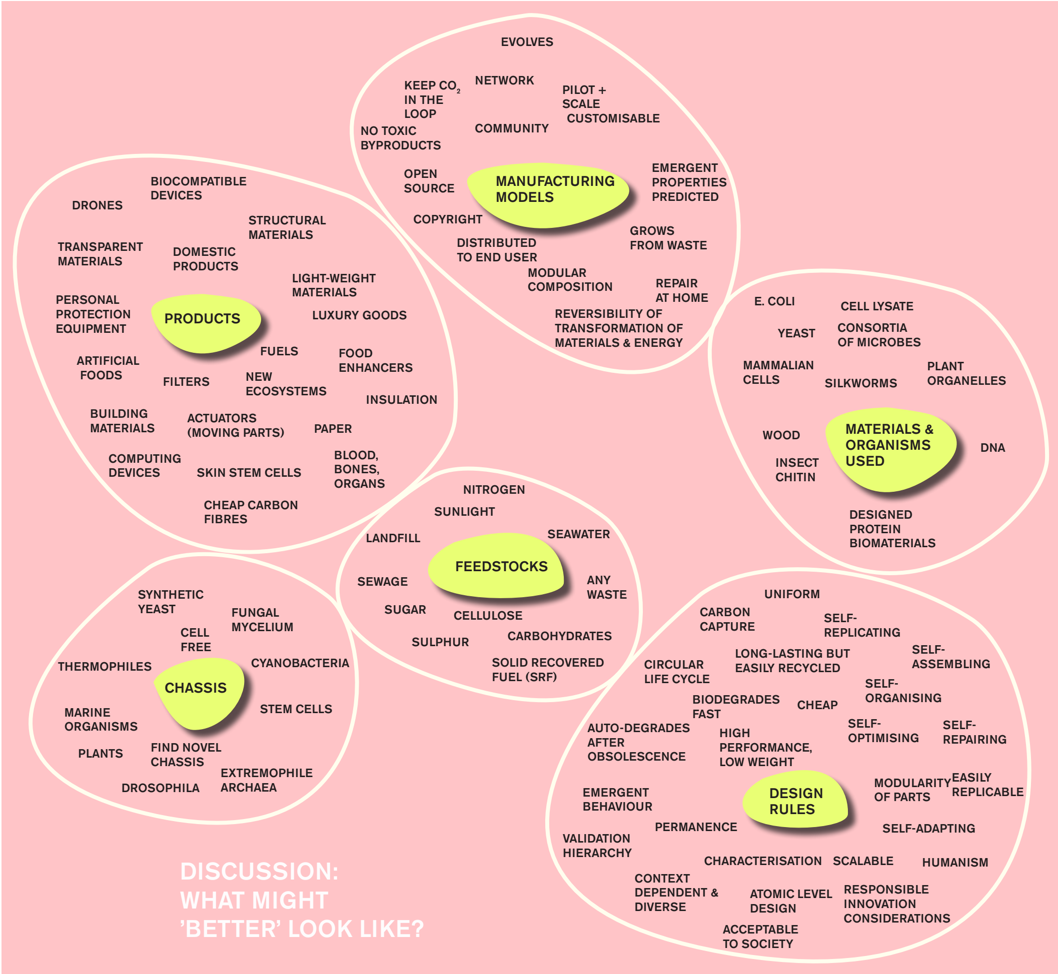


Figure 3.7
The workshop elicited a more granular discussion around "better" synthetic biology, ranging from organisms and feedstocks to products.

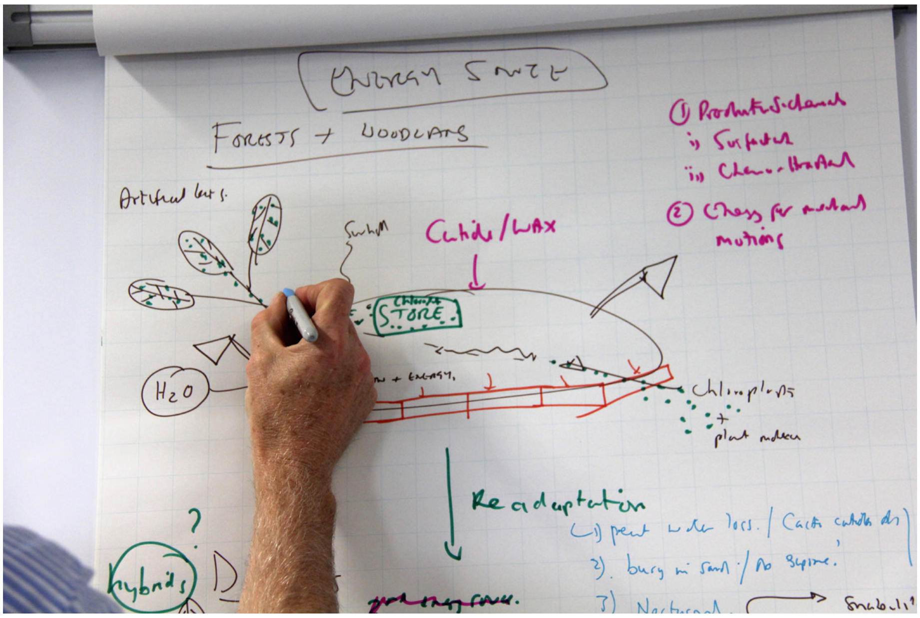
principles such as mutation, or new ownership infrastructures (figure 3.6). Contrary to the official *Roadmap's* industrial values, figure 3.7 shows that some synthetic biologists in this industrial centre still idealise the more democratic imaginary described in Chapter 2.

Could critical design techniques help synthetic biologists articulate these discrepancies? I asked the participants to depart from current science to consider how a biological vehicle might function by having to repair it. I wanted them to reverse engineer a future synthetic biology. Doing so revealed ideological tensions. Their designs were far more radical and playful than I expected. I had predicted biofuel engines, but was presented with slow-moving "slugmobiles" and "muscle" cars (figures 3.8-9). Their fantastical vehicles conflicted with their demands to focus on "reality". Jon Turney (2014), an invited speaker, commented that this imaginative activity still revealed an engineering vision too focused on "fashioning/growing actual artefacts"; engineering solutions seemed to preclude synthetic biologists from really taking inspiration from biology. Could literal substitution ever deliver true change?

I wanted to make these issues tangible in the *Dezeen* and MINI exhibition, so I translated the synthetic biologists' aspirations for best practice into a system. To avoid didacticism, I subjected design to biological rules, rather than biology to design. The final installation, *Design Taxonomy*, suggests an alternative model of sustainable production for car design and manufacture. Inspired by the Turtle 1 (see Chapter 1), top-down corporate design uniformity was replaced by bottom-up, consumer-led design, distributed manufacture, diverse materiality, and repair (figure 3.10).

In this scenario, biodegradable materials that can be cheaply and efficiently exchanged, whether wood or engineered biomaterials, replace metals and plastics. Car companies would no longer produce entire vehicles, but manufacture and distribute a durable chassis, onto which disposable, locally produced "bio-shells" could be added. These could be changed depending on local climate, use, or taste. Adaptation, mutation, and evolutionary patterns would start to emerge in the design (figure 3.11). The exhibit showed one car diversifying over thirteen generations and across five climate zones to produce over one hundred different designs (figures 3.12-13). Exemplary "type specimens" chosen by the car company would be copied and improved upon locally. Designed by context, the vehicles would have life cycles not lifespans, encouraging repair and adaptation. The 113 model cars (figure 3.14) were displayed on multiple plinths, alongside drawings of the production life cycle and the taxonomy of "evolving" cars, and *Dezeen's* film following the project's development (Hobson 2014c). In this future, redesigning living things instigated a rethinking of conventional design and manufacturing systems.

The imaginary of sustainable abundance, so desirable to industry and policymakers, has been globally extended without official challenge. My workshop revealed the dichotomy between policy visions and individuals' values that were often more democratic than the industrial reality. Participants spotted this inconsistency, as their biological cars departed from the official better, triggering discussion. The *Design Taxonomy* installation made tangible how far the industrial vision is from delivering a disruptive, sustainable abundance. When I documented the work for SynbiCITE in a final report (figure 3.15), I called it *Alternatives Roads*, indicating divergence from the official *Roadmap*. Cheerfully critical, this project seemed to have little impact on others, an issue examined in Chapters 5 and 6.



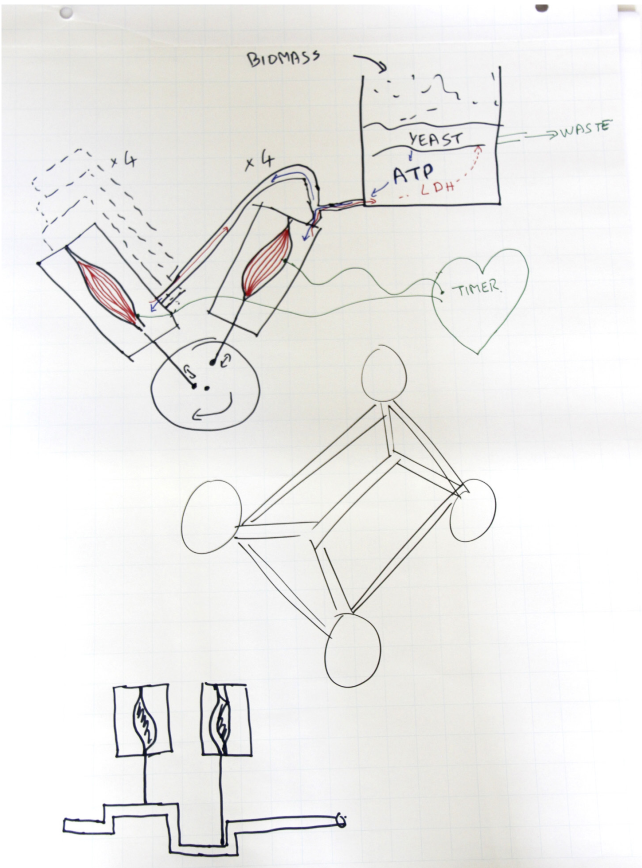


Figure 3.8
The Bio Road Trip design exercise asked workshop participants to reverse engineer a biocar, with results like this “slugmobile”.

Figure 3.9
This car made from muscle fibre was designed by the group whose biocar had run out of energy. Many of the groups’ designs contained parts that were replacements for mechanical parts, like wind-up motors, but made from biology.

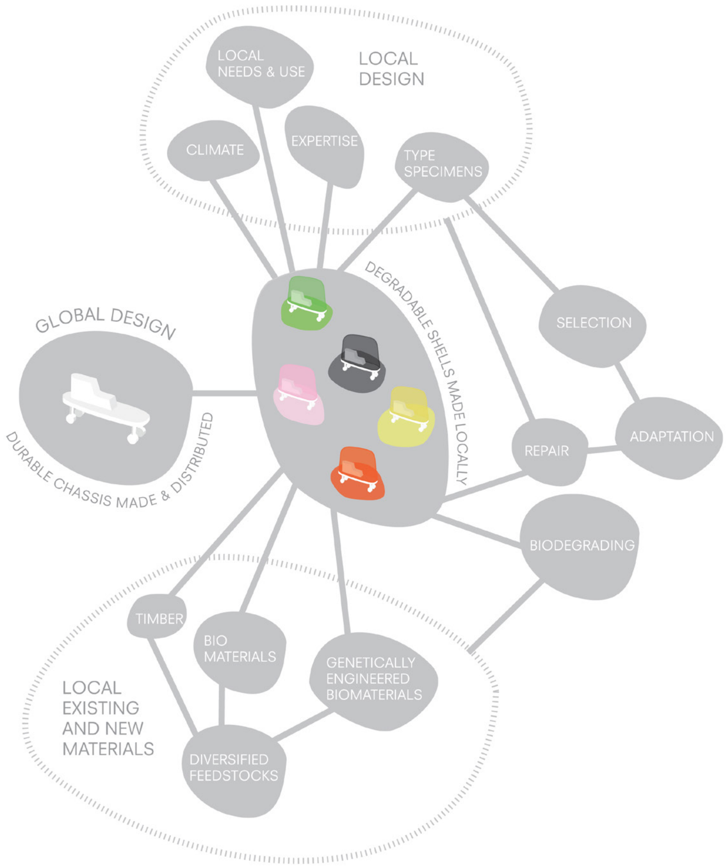


Figure 3.10
Design Taxonomy (2014) presents an idealised production system that explores sustainable manufacturing using biological materials, distributed design and making, and repair.

Figure 3.11
This conceptual sketch from June 2014, prior to the workshop, explores my early idea of cars' design diverging over time, due to climate. Referencing a tree of life drawing that shows biological evolution and diversity over time in a 3D space, I was interested in expanding design's possibility space. Instead of resorting to genetic algorithms to generate ideas, could we let design itself go “wild”?

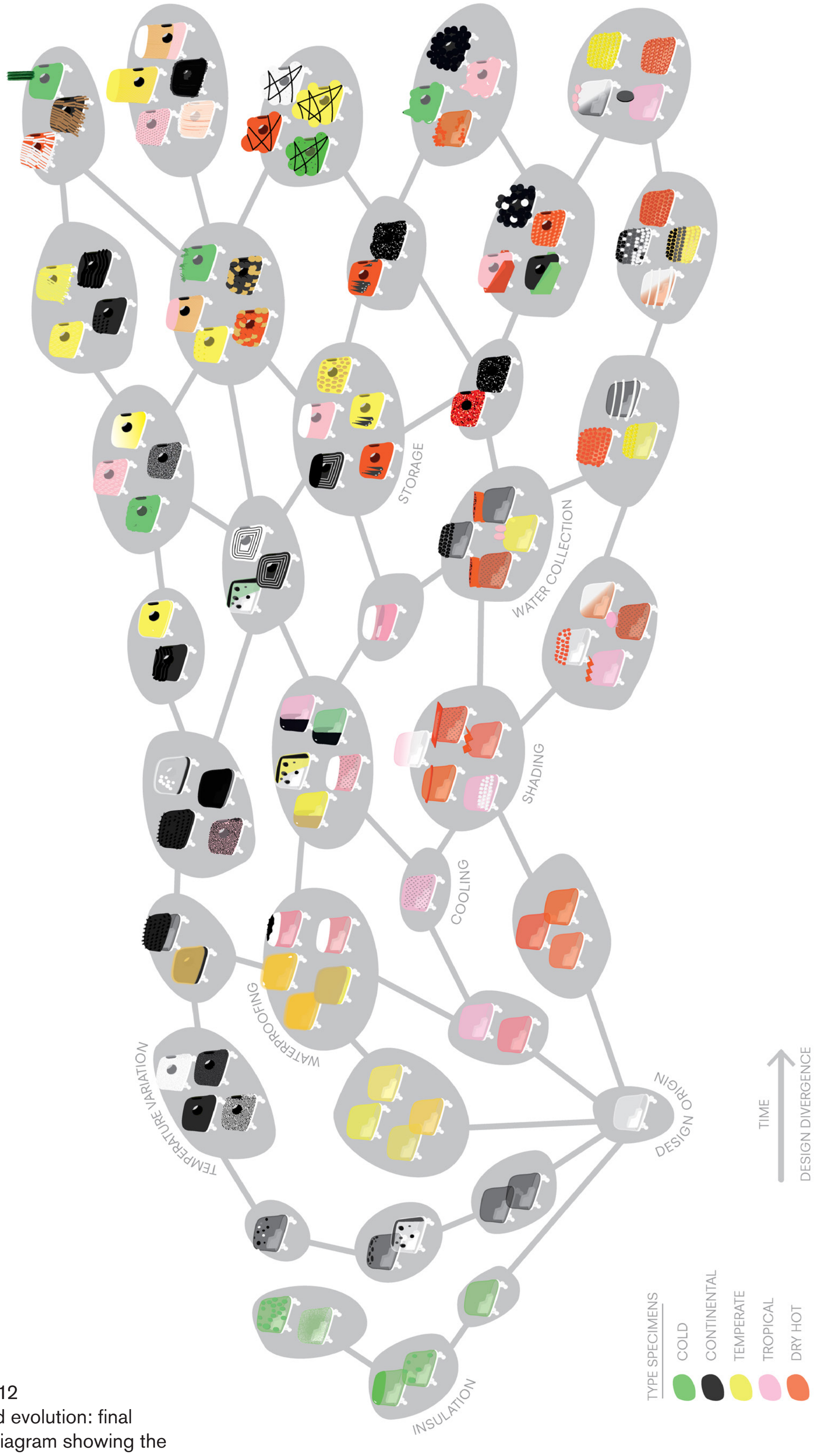


Figure 3.12
Designed evolution: final system diagram showing the basic car design diversifying in 112 ways over thirteen generations and across five climate zones in *Design Taxonomy* (2014).

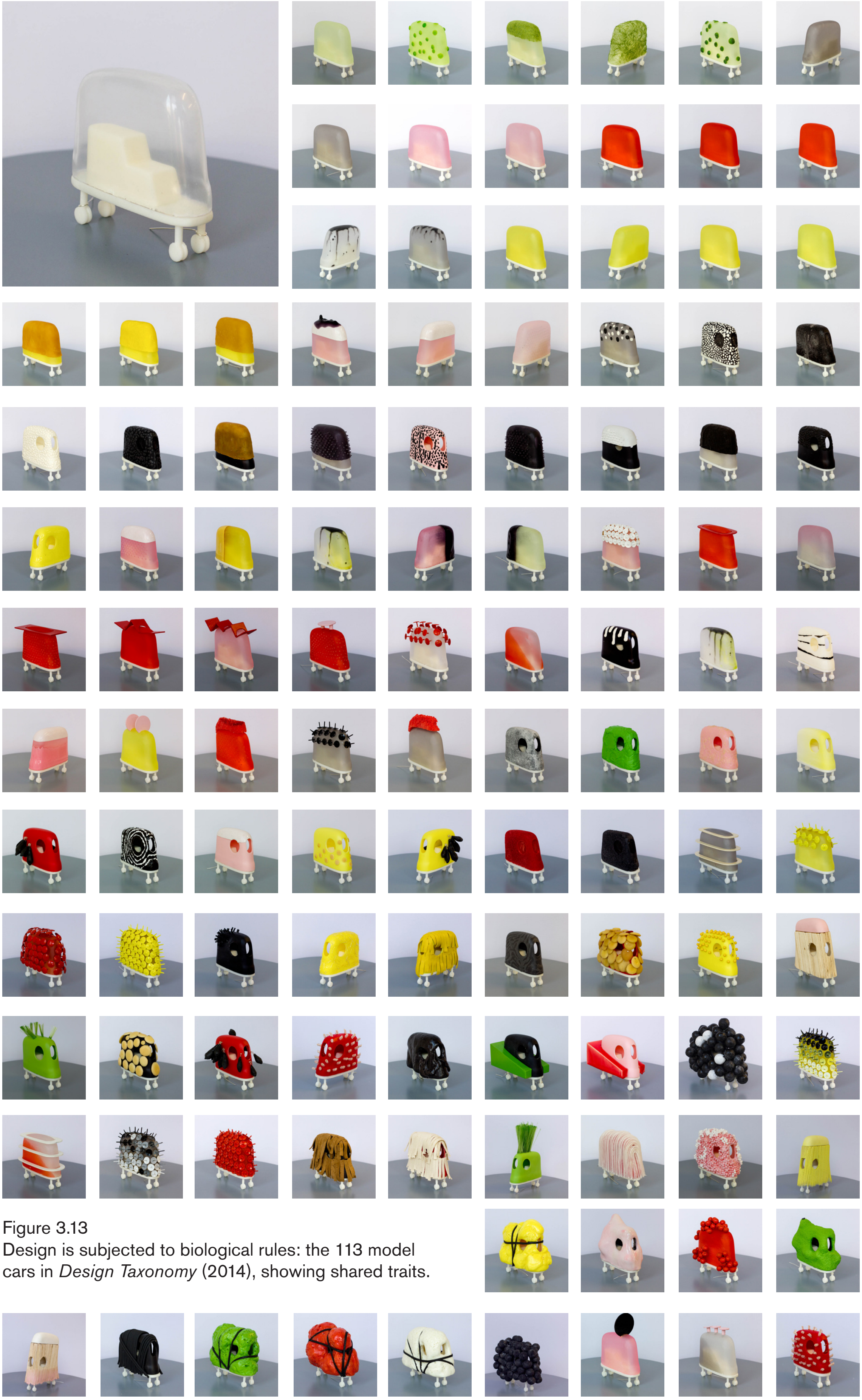


Figure 3.13
Design is subjected to biological rules: the 113 model cars in *Design Taxonomy* (2014), showing shared traits.

Figure 3.14
Installation view of *Design Taxonomy* (2014) at the "Dezeen and MINI Frontiers" exhibition, Design Junction, London, September 2014.

Figure 3.15
Sample spreads from my *Alternative Roads* report (2015) for SynbiCITE. The report, intended to provoke new ideas, was laid out in a magazine-like format to distinguish it from more formal documents.

Alternative Betters

In early 2014, before I began work on the MINI project, Keasling had conceded that "We're never going to have biofuels compete with $20-a-barrel oil—period" (LaMonica 2014). Even with funding from Silicon Valley investors, the microbes could not compete at scale with artificially low oil prices.[27] Amyris—and other companies—tweaked their organisms to secrete high-cost, low-volume pharmaceutical chemicals, flavours, fragrances, and expensive cosmetic ingredients (Pollack 2013; Check Hayden 2014).[28] Faced with material constraints and economic strictures, sustainable abundance now meant chemicals previously sourced from nature.

Whether producing fuel or flavours, industrial synthetic biology may only deliver a better future for some. A growing resistance to the imaginary began to reveal the existence of other betters: those of the disrupted. Fans of disruptive innovation tend not to dwell on the disrupted, whether corporations, federal coffers, or unprotected workers. Civil society organisations like the Canadian ETC Group (2011; 2015), challenging the field since 2006, defended the farmers of valuable crops like sweet wormwood or vanilla beans, or those living on what Keasling erroneously referred to as "unused" or "marginal" lands for sugar farming.[29] The NGOs believed that the industry's top-down structure, led by incumbent corporations, would heighten social inequality (figure 3.16).[30] Even the vision of the bioeconomy itself was widely contested (see Ponte & Birch 2014). Using crops to make plastic and biofuel risks pushing up food prices, using land and resources, too.[31]

Keasling's flagship artemisinin project became a major flashpoint (e.g. Carlson 2013; Thomas 2013). Synthetic biologists—including Keasling—refuted concerns about anti-malarial drug supply, questioning how critics could prioritise the livelihoods of a few thousand wormwood farmers over the millions of lives potentially saved. Social scientist Claire Marris (2013), then working with SynbiCITE, warned that the field's image risked being tarnished if it continued to

27 Amyris had received $20m for fuel development from Khosla Ventures. Keasling now hoped one day to be able to compete with "$100-a-barrel oil" (LaMonica 2014).

28 Beyond making single ingredients to add to cosmetics, Solazyme launched Algenist, a luxury algae-based skin-care brand (Saint Louis 2011). Branded "Biotechnology from San Francisco", its Genius Anti-Aging Cream sells for £85. I was surprised to see GMOs in the beauty sector marketed alongside products that trade off their organic provenance; perhaps this isn't seen as problematic since this industry sells departure from the natural to "defeat" ageing.

29 At the second synthetic biology conference, SB2.0, in 2006, 36 civil society groups including the ETC group presented a letter calling for public discussion of the emerging field (Campos 2009, p.19).

30 In this battle for what better meant, Thomas shared some beliefs around open innovation with Endy. Stewart Brand (2008) wrote of a Long Now conversation between Endy and Thomas: "For different reasons, both debaters wanted to see Synthetic Biology kept from domination by commercial patents. For Thomas, it would lead to unjust monopoly answering only to profit. For Endy, it would paralyze open-ended research."

31 These crops increase pressure on land and water, are farmed using monoculture agricultural practices linked to deforestation and biodiversity reduction, require fossil fuels for machinery and chemicals, and use nitrogen-based fertilisers causing soil acidification and dead zones in rivers and oceans (see Ponte & Birch 2014). Conventional agriculture, which often includes agricultural biotechnologies like genetically engineered crops is, for sociologist Thomas A. Lyson (2002), a reductionist, scientific paradigm based in neoclassical economics: the goal is simply to intensify productivity through the specialization, economic competition, and the "domination of nature". Lyson defends sustainable agriculture's different focus, operating in "harmony with nature", enhancing biological diversity and community.

over-promise without acknowledging the situation's complexity. At meetings, I observed the community's disavowal of debate.[32] Yet Keasling's planned market monopolisation to control and meet global supply of artemisinin, which he openly discussed, has not materialised;[33] the conflict was for naught, while rejection of critique reveals whose better was being served. The imaginary of sustainable abundance blinded this vanguard to the complex political, social, and economic realities around biofuel and pharmaceutical production and distribution. A vision and a working technology are not always enough.

Consumer resistance to these claims of better soon emerged. In 2014, Ecover, the world's largest green household cleaning products company, announced trials of a more sustainable detergent ingredient made from algal oil, replacing palm kernel oil (figure 3.17) (Carrington 2014; Ecover 2014). *The New York Times* revealed that synthetic biology firm Solazyme was producing the oil, making Ecover an unlikely synthetic biology pioneer (Strom 2014). Activists and consumers raised objections around labelling, biological escape, and farmers' livelihoods. Evaluating supply chains is complex: how do you determine whether Brazilian sugarcane farming is better than Indonesian palm farming (Ginsberg 2015)?[34] The furore sparked a denial from Ecover that they were using synthetic biology, but just "natural mutation" and "fermentation"; the trial was shelved (Domen & Develter 2014).

In the marketplace, better clearly had meanings far beyond the vanguards'. Solazyme, who as early as 2009 had revamped itself from a "synthetic biology company" to "the leading renewable oil and bioproducts company" engaged stakeholder groups.[35] Ecover asked Forum for the Future (FftF), a sustainable development NGO, to investigate whether synthetic biology could contribute to a sustainable future (Warrington 2015a).[36] FftF concluded that sustainability depended on each application (Warrington 2015b; FftF 2015).[37] Their design of a 79-page "deliberation aid" for each future application shows the complex reality: there is no universal better.

32 Marris (2015, p.85) wrote: "There is no recognition that the definition of societal benefits, and the way in which synthetic biology will contribute to them, might need to be opened up to deliberation. Supporters of synthetic biology advocate communication and dialogue, but not debate where people could disagree about what is at stake."

33 Discussed at the 2013 conference "How will synthetic biology and conservation shape the future of nature?" in Cambridge, see Chapter 4. Synthetic biologist Henry Stennett (2017) evocatively captures the controversy around synthetic artemisinin.

34 Who defines sustainability is contested outside of synthetic biology, as well. While the ETC Group pushed for coconut oil to be used instead, SynBioBeta editor Maxx Chatsko (2014) reported Solazyme's claim that algae fed on sugar produced significantly more useful myristic acid, a key ingredient in detergents, etc., than oil derived from the same area of palm or coconut grown for oil. For research, see ETC Group (2013a).

35 Solazyme's public shift from being a "synthetic biology company that unleashes the power of marine microbes" occurred between 16 April 2009 (2009a) and 10 October (2009b), according to the Internet Archive Wayback Machine. Despite publicising its own efforts at transparency in an article called "Can algae save the orangutans?" (Haiken 2015), Solazyme's new website (2016) explains that "we survey mother nature to select the best traits to place back into the microalgae". Synthetic biology is only mentioned as one of a number of technologies in a section called "Responsible Innovation".

36 I contributed some comments (Ginsberg 2014c). The project was mainly funded by the UK's BBSRC and the research conducted with the BBSRC and Friends of the Earth England Wales Northern Ireland.

37 FtfT's earlier report, *Sustainable Returns: Industrial Biotechnology Done Well*, suggested ten aspirational commandments for achieving sustainability (Porritt 2013).

Figure 3.16
“Welcome to the New Global $ugar Economy” (2009), by the ETC Group.

Figure 3.17
“The Palm Oil Problem. And the Algal Oil Solution” (2014). Ecover published this infographic advocating for synthetic biological algal oil; the web page was deleted after the trial was pulled due to consumer and NGO backlash.

But burgeoning consumer resistance triggered a shift towards obfuscation. In 2014, the Wilson Center's Synthetic Biology Project published *A Guide for Communicating Synthetic Biology*, advising how to shape messages towards projected benefits (Mazerik & Rejeski 2014), seemingly weighting information towards synthetic biologists' betters.[38] "Fermentation-derived" and "nature-identical" were substitute terms recommended at Consumer Bio (2015), an invitation-only conference.[39] Even Synberc dropped synthetic biology from its name, becoming the Engineering Biology Research Consortium in 2016 (EBRC 2016). Keasling said this reflected how the "federal government and others are referring to our field" (Endy 2015). But removing transparency only serves the field's better.

Obfuscation makes it harder for consumers to make their own choices. In 2013, activists resisted Swiss-based Evolva's synthetic vanillin, secreted by engineered yeast (ETC Group 2013b). The NGOs claimed that Madagascan vanilla bean farmers would be undercut by Evolva's vanillin, which, unlike "synthetic" vanillin, could be labelled as "nature-identical" or perhaps "natural".[40] Evolva (2014a) claimed it was only competing with cheap synthetic vanillin, not beans. Although Evolva sells to other businesses, to try to avoid future controversy it recalibrated its marketing towards the consumer, promoting how their technology will better our lives (Goldsmith 2016). An animation of a woman called Joy (figure 3.18), baking in her kitchen, features on Evolva's home page (2014b). Joy challenges scientist "Eve" to explain why anyone would "tweak" natural yeast (see Marris 2015).[41] Eve explains that Evolva focuses on ingredients with "issues", like those made from petrochemicals or rare animals. Contrary to Evolva's avowal, Eve describes their vanilla as "more sustainable, more natural", stopping deforestation in Madagascar (Evolva 2014b).[42] Evolva is invoking sustainable abundance and trustworthiness, but preventing consumers evaluating for themselves what is better.

By contrast, Ginkgo Bioworks, a Boston start-up co-founded in 2008 by MIT's Tom Knight and four of his graduate students, advocates transparency.[43] Weeks before announcing $100m in venture capital funding, CEO Jason Kelly (2016) wrote an opinion piece, "I run a G.M.O company—and I support G.M.O labeling" for *The New York Times*, addressing the raging US debate over labelling GMO foods. Ginkgo hoped transparency could avoid future clients being outed like Ecover. Economically motivated, this approach still allows consumers access to reality.

38 The Wilson Center is a non-partisan policy forum chartered by US Congress that has studied synthetic biology since 2008.

39 For commentary on this meeting, see Malkan (2016), and Zhang (2015).

40 According to Evolva, 99% of vanilla flavour is made from petroleum or the by-products of papermaking (McEachran 2015). Madagascan vanilla farmers contribute to the remaining 1%. Evolva's vanillin is produced by modified biology, but the vanillin is not itself a GMO: hence the labelling potential. Friends of the Earth petitioned to persuade ice cream manufacturers to drop synthetic biologically-produced vanillin, with brands such as Häagen-Dazs capitulating (see Friends of the Earth 2013; Colwell 2014; McEachran 2015).

41 "Eve" evokes Edenic abundance, but, as Luis Campos reminded me, Eve is the one woman you shouldn't trust.

42 Evolva CEO Neil Goldsmith (2016) created distance from synthetic biology in his talk at SynBioBeta London 2016. He was not alone: a panel of investors also emphasised how they avoid the term.

43 Ginkgo does "biology by design" in their roboticised labs, including designing yeast to secrete chemicals for the flavour and fragrance industries, and working with DARPA on probiotics. Ginkgo's cofounders advised MIT's iGEM 2006 team, who engineered *E. coli* to smell of banana and mint. In 2016, Gingko was seventh in CNBC's "Disruptor 50" list (CNBC 2016), raising $100m in series C funding (Herper 2016).

Figure 3.18
A scientist called Eve explains fermentation to a concerned woman in a promotional video on Evolva's (2014b) home page, a part of their communication strategy to increase trust in synthetic biology.

Activists' resistance has rightly revealed the existence of other betters, but they don't suggest how to accommodate them in synthetic biology. Instead, they argue for the precautionary principle, essentially stopping research (ETC Group et al. 2012).[44] Evolutionary biologist Richard Lewontin (2014) argues that this makes progress impossible. There is no better for all: synthetic biology will disrupt someone. Yet individually evaluating each product to establish whether they are better, for whom, seems impossible in practice. If we seek transformation of existing systems towards real sustainability—as these NGOs claim to by defending other betters—we must consider how, and if, synthetic biology could be used appropriately to contribute. A first step requires the synthetic biology industry to acknowledge the complexity of the global systems it promises it can better, and to be transparent about the technology, and whose better is being served, or denied. Synthetic biologists' imaginary of sustainable abundance should not be extended at the expense of real sustainability.

44 In 2012, 111 civil society groups collaborated on *The Principles for the Oversight of Synthetic Biology*, which called for the precautionary principle (ETC Group et al. 2012). The principle states that in the absence of scientific consensus that a policy or action is not a risk to the public or environment, it should not be pursued (European Commission 2000).

3.3 Conclusions

From 2006, the dream of bettering biology using synthetic biology was industrialised by visionaries, who promised a better future of sustainable abundance. This industry adopted Silicon Valley's betters, tangling together the common good, economic growth, and technological progress. To extend their vision globally, this vanguard reaped investment from governments seeking economic returns, from Silicon Valley, and from the very industries they hoped to disrupt. But this industrial better exists uneasily in parallel with Chapter 2's open-source better: Randy Rettberg closes iGEM each year saying, "This is the beginning of a new industry, and people at iGEM will start that industry. I expect you to have the startups, I expect you to have the private jets, and I expect you to call me up and offer me a ride."[45]

The promise that synthetic biology's biocapital will automatically contribute to human flourishing is deeply problematic. Critiques of rising inequality lodged at neoliberalism also blemish synthetic biology; NGOs have highlighted how others' betters are at risk. A concerning response has been the diminishing of transparency, which heightens the risk of future backlash. Critique carries a risk of ejection: outsiders like the NGOs are no longer welcome, while critical insiders like Rabinow and Marris have left the field (see Balmer et al. 2015, pp.12-13). Acceptance cannot be the only permitted response. While my projects "Alternative Roads" and *Design Taxonomy* were quietly critical and thus uncontroversial, they helped me to dissect and make tangible this imaginary of sustainable abundance. Chapter 5 will show how designers need to be wary of this dream.

In this chapter, synthetic biology was isolated in vats, fed from nature, but separated from it, disrupting without disrupting. The next chapter uses my critical design work to identify a third dream of better: one that integrates synthetic biology into nature, challenging what better means for nature itself.

45 I heard him repeat this in his speech in person at iGEM 2009 and 2010. Others report it too (e.g. Lichenstein 2007).

Chapter 4. Better Nature

4.1 Introduction

"You're pushing against a huge open door, and I invite you to walk through," synthetic biologist Paul Freemont told the conservationists, adding: "And do please cheer up just a little bit" (Yong 2013). Freemont was addressing an auditorium at the University of Cambridge filled with leading synthetic biologists and conservationists, gathered for the first time to discuss "How will synthetic biology and conservation shape the future of nature?" (Wildlife Conservation Society 2013).[1] Having asked to attend this sometimes tense meeting, I was struck by the two groups' very different views on better. The conservationists were pessimistically looking backwards to protect biodiversity from humanity, while optimistic synthetic biologists like Freemont looked forwards, designing new biodiversity to benefit that same humanity (figure 4.1).[2] Their interests had momentarily converged, but would the future survival of one field preclude the other?

The conservationists wanted to know whether the release of synthetic organisms, intentional or not, would become yet another problem for them. Or could the two groups work towards a shared future? Humans have potentially triggered the sixth great extinction event in the history of biology (Kolbert 2014); could synthetic biologists now design organisms to protect nature, essentially "infecting" it to save it? This discussion spawned my critical design fiction *Designing for the Sixth Extinction*, which I use in this chapter to explore synthetic biology's third, more radical and troubling dream of better: that of bettering "nature" itself. This chapter examines how this imaginary is being embedded in the design of living biological things, considers the ideologies underpinning it, and the issues its designs raise. I first introduce efforts to change human nature through genetic modification; next I discuss designing to eliminate natural species, and then synthetic biologists' dreams of making nature "better" by saving or resurrecting wild species or even inventing new ones, using my project *Sixth Extinction* to investigate more deeply. Finally, I reflect on the imaginary's modernist ideology, which implies that humans can control biology to "solve" it, neglecting to view us as part of nature, and thus part of nature's problem.

Sixth Extinction makes tangible dreams of improving nature, long in the cultural and scientific imaginary and now being galvanised by technological advance. When I began *Sixth Extinction* in April 2013, I knew little of CRISPR-Cas9, a programmable genome editing system published

1 The meeting was organised by conservationist Kent Redford for the Wildlife Conservation Society (see Redford et al. 2013). For *Nature's* report, see Callaway (2013).

2 Attendees compared the meeting to a first date, as they sought out common ground, trying to keep conversation flowing. Redford joked: "Conservationists get more pessimistic when they drink, but synthetic biologists only get more optimistic" (Yong 2013).

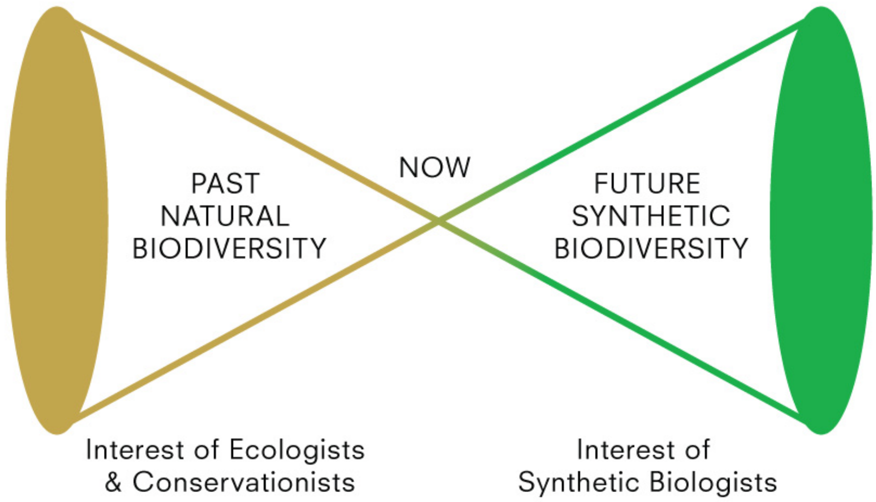


Figure 4.1
At the 2013 conference, I noticed that the conservationists' and synthetic biologists' diverging betters were momentarily converging. A version of this sketch was my starting point for *Designing for the Sixth Extinction*.

Image redacted for copyright reasons
Available at: https://www.wired.com/wp-content/uploads/2015/07/designer_genes_cover.jpg

Figure 4.2
WIRED magazine's August 2015 cover is typical of media reports on CRISPR and its implications. The altered landscape background photo is by Richard Mosse, shot on infrared film.

by Jennifer Doudna and team in *Science* the previous August (Jinek et al. 2012),[3] followed in January 2013 by the first papers using it to edit the human genome (Mali et al. 2013; Cong et al. 2013).[4] CRISPR refers to a cluster of DNA sequences found in bacteria, which use them to spot and cut up the DNA of invading viruses based on a stored copy of the virus's sequence. Being able to programme CRISPR to "search and replace" DNA was the breakthrough. This precision makes CRISPR potentially the biggest advance in genetic engineering since recombinant DNA techniques were invented in the 1970s, prompting hyperbolic reporting (figure 4.2) (e.g. Maxmen 2015). CRISPR is certainly cheap and fast, and appears to work well in any species. "It's like you throw a piston into a car and it finds its way to the right place and swaps out with one of the other pistons—while the motor's running", explains pioneering synthetic biologist George Church (Interlandi 2015). But it is not as reliable as the hype implies, and precise editing doesn't automatically equate to better understanding or control of living matter (Kaiser 2016). How much control can we have? How much do we need before we release such technologies?[5] Who decides?

As synthetic biology products, some CRISPR enabled, are coming to trial and market, governance is struggling to keep up. How we define better, and how we design an equitable system in the face of such social and ecological complexity, is a huge challenge. As this vanguard tries to decouple biology from nature to save us from it, and it from us, will the nature we imagine still exist?

4.2 Making Nature (And Us) Better

Changing Nature

Eighty years after plant breeder Luther Burbank proclaimed that "Man Can 'Go Nature One Better'", the US President's Council on Bioethics (2003, p.290) questioned whether "biotechnology may be able do nature one better". Genetic modification of living humans was in its infancy: the difficulty of inserting genes in the right place, the complexity of their interactions, and the environment's impact on those genes made bettering unborn humans seem impossible in both "practice" and "principle" (2003, p.38).[6] Still, the council warned of a future

3 CRISPR stands for clustered regularly interspaced short palindromic repeats. CRISPR-Cas9 is one complex, other systems using different nucleases have since been published.

4 CRISPR's usefulness has made CRISPR-Cas9 the subject of a fierce and complicated patent dispute involving three start-ups (Editas Medicine, Intellia Therapeutics, and CRISPR Therapeutics) and a number of universities, including the institutions of the lead authors of two papers published on it. Jennifer Doudna of UC Berkeley and Emmanuelle Charpentier, now at Umeå University, first published their work in August 2012 in *Science* (Jinek et al. 2012). Feng Zhang at the MIT-Harvard Broad Institute published in February (Cong et al. 2013), in the same issue of *Science* as the Mali paper, submitted a month after Zhang's. While Zhang published later than Doudna, both claim the key breakthrough. Doudna submitted her patent in May 2012, Zhang in December 2012, but under fast track review; Zhang was awarded the patent in April 2014. As of writing, IP claims are still being challenged (Begley 2017).

5 In a *Nature* feature on CRISPR, science policy expert Eleonore Pauwels cautions: "I think there is a lot of value in humility about how much control we have" (Reardon 2016, p.161).

6 In 2002, a gene therapy trial had caused leukaemia after a cancer-producing gene was possibly switched on (Marshall 2002).

dual-use technology that could alleviate suffering, but might also be used to strive for human perfection. Its chairman, scientist turned bioethicist Leon R. Kass, worried "whether life will really be better if we turn to biotechnology to fulfil our deepest human desires" (2003, p.17).

"I am patient zero. I will be 45 in January. I have aging [sic] as a disease", wrote Elizabeth Parrish (2015), CEO of start-up BioViva Science USA Inc. on a Reddit AMA (Ask Me Anything) chat session in October 2015. Parrish, who is not a scientist, claimed to be undergoing two kinds of gene therapy, including being injected with viruses containing genetic instructions to produce the protein telomerase. Telomerase extends telomeres, the caps on our chromosomes that shorten after each cell division, often described as the body's ageing clock. To avoid the FDA in her quest "to reverse biological ageing", she had her unregulated treatment in Colombia (Regalado 2015a). In April 2016, BioViva (2016) announced that Parrish's trial-of-one had reversed "20 years of normal telomere shortening".

Experts questioned BioViva's methods, results, and evasion of regulation (Warmflash 2016). But some remain excited about the prospect of changing our natural selves. "The extension of life span is quite dramatic in model organisms ... it would be amazing in humans", George Church told regulators (Regalado 2015a). Church was—and is—one of BioViva's scientific advisors (Mohammadi & Davis 2016).[7] Trained as a biologist, he describes himself as an engineer who does some science (Interlandi 2015).[8] In his provocative popular science book, *Regenesis: How Synthetic Biology Will Reinvent Nature and Ourselves*, Church (2012, p.13) promised that "synthetic genomics" would restate the course of evolution as we knew it. Rather than the "blind and opportunistic processes of natural selection", he declared evolution under human control (2012, p.13). CRISPR was as yet unpublished; still, he claimed that "We are already remaking ourselves and our world, retracing the steps of the original synthesis—redesigning, recoding, and reinventing nature itself in the process" (2012, p.13). Just a decade after the Council's speculations, biotechnology was doing nature one better.

Although an academic, between 2005 and 2015 Church "launched" fifteen bioengineering companies and advised many others (Interlandi 2015). Church (2016) sees this as means of "accelerating the pace at which technology is transferred from an idea to an experiment... from a paper to a company, from a company to the market".[9] Like the imaginary of sustainable abundance, the vanguard's dream of bettering nature is being embedded and globally extended through new companies and markets.

CRISPR is hastening genome editing's move into funded start-ups and human trials.[10] The speed has prompted internal resistance as its inventors advise regulators: in late 2014, a

7 Church recommended BioViva follow proper channels, distancing himself from them in July 2016. He told *The Guardian*: "I advise people who need advice and they clearly need advice" (Mohammadi & Davis 2016).

8 Church (2015) says his work on direct genome sequencing in the 1980s "contributed to nearly all 'next generation' DNA sequencing methods and companies". It helped to bring down whole genome sequencing costs from billions to thousands of dollars (Interlandi 2015).

9 Highlighting his links with industry, Church opens every presentation with an infamous "conflict of interest" slide, crammed with corporate and government agency logos (Campos 2012, p.116).

10 By 2016, Church and Zhang's CRISPR company Editas has over $200m in cash to spend, with plans to run human trials by 2017 (Byrnes 2016).

concerned Doudna (2015a; 2015b) stepped into the ethical debate about modifying humans.[11] Although editing the human germline—embryos, sperm and eggs—was already banned in many countries, in early 2015 some experts, including Doudna, called for a moratorium due to the lack of knowledge of its long-term effects (Lanphier et al. 2015). Church and others meanwhile "strongly discourage[d]" the technology's development for clinical applications, to make time for discussion (Baltimore et al. 2015). After Chinese researchers announced in April 2015 their use of CRISPR on non-viable human embryos (Liang et al. 2015), the US National Academies of Science, Engineering and Medicine and their Chinese and UK counterparts (US NASEM et al. 2015) convened an International Summit on Human Gene Editing in December 2015, which proposed ongoing discussion, but no ban.[12] Sheila Jasanoff et al. (2015) criticised the summit, calling for a process of truly inclusive societal deliberation to recognise that "technology's unimpeded progress is not the only collective good recognized by free societies".[13] Nevertheless, in 2016, the first UK embryo editing experiment was approved (Vogel 2016), and Chinese researchers began trials on live lung cancer patients (Woolf 2016).

Could better biology better our "natural" selves? Dreams of eliminating disability or disease, extending life, and editing our own or our descendants' bodies for health or looks are rife with ethical and social implications, religious arguments, and scientific unknowns.[14] Some disagree. "Get out the way", psychology professor and proponent of human progress, Stephen Pinker (2015), declared. "A truly ethical bioethics should not bog down research in red tape, moratoria, or threats of prosecution based on nebulous but sweeping principles such as 'dignity,' 'sacredness,' or 'social justice'", he argued, dismissing reference to eugenics or designer humans. Interviewing Pinker, stem cell scientist Paul Knoepfler (2015a; 2015b) found his focus on promised benefits flawed, since it avoided the unknowns troubling even CRISPR researchers. This "genohype" obscures the reality that our biology is not just DNA (Holtzman 1999), promoting the imaginary that humans can control biology.[15] CRISPR is progressing gene therapy,

11 By February 2014, monkey embryos had been modified in China (Larson 2014). Alarmed, Doudna (2015b) describes in "My whirlwind year with CRISPR" how she was unprepared to deal with the ethical outcomes of her research, and called for scientists to receive more training to deal with talking about their work, including improving their "elevator pitch". But training should be in communication, as well as in humanities and bioethics. See Ledford (2015a) for more on concerns.

12 The 2016 summit ruled out *banning* gene editing viable embryos, but it said it was unacceptable without more research and societal discussion. But after just over a year, the US NASEM (2017) changed their position, announcing in February 2017 that "Heritable germline editing clinical trials could one day be permitted for serious conditions; non-heritable clinical trials should be limited to treating or preventing disease or disability at this time".

13 Curator Nicola Triscott (2015), attending, also decried the lack of diversity, calling for other voices to be included, including artists'.

14 There is not room to delve into these issues here. For introduction to the issues of transhumanism and the ethics of bettering humans, see bioethicist Allen Buchanan's *Better Than Human* (2012) and *Beyond Humanity* (2013). For a pro-bettering argument, see *Enhancing Evolution: The Ethical Case for Making Better People* (Harris 2007). See also *Nature's* sobering report of a physician-scientist at the University of California, San Francisco, and his young daughter, who has albinism. The father assumed he would have edited out her "faulty" gene, but was profoundly changed on learning that his daughter wouldn't have (Check Hayden 2016).

15 In 2016, Sean Parker, Silicon Valley billionaire and Facebook's first president, announced he was funding the first human CRISPR gene-editing trial in the United States (Regalado 2016a). For more on genohype, see Zurr (2005).

but editing *in vivo* is still causing unintended mutations (Schaefer et al. 2017).[16] The imaginary that we can better our nature neglects biology's complexity, and obscures debates about what constitutes a better human, who decides, and who would be bettered by this technology.

Eliminating Nature

Instead of changing ourselves, some want to eliminate nature to protect us from it. Oxitec, a UK company, has engineered *Aedes aegypti*, the mosquito species that carries dengue, Zika, and chikungunya viruses.[17] Their Friendly™ Aedes male mosquitoes are bred in factories, hand-sorted and released to mate with wild females. The offspring inherit a fluorescent identification marker and a "self-limiting gene" that kills them before they become functioning adults (Oxitec 2016a). In theory, the species disappears "without a trace" (LaFrance 2016). Is the optimum mosquito *no* mosquito?

Oxitec is embedding this imaginary of bettering nature into designed organisms, and extending it globally by releasing them.[18] Intrexon Corporation bought Oxitec in August 2015. In January 2016, the US Centers for Disease Control and Prevention announced a link between Zika infection and the birth defect microcephaly, and Intrexon's shares soared by 73% in a day (B. Schmidt 2016). Oxitec (2016a; 2016b) extended its small trial in Piracicaba, Brazil, which had reduced wild mosquito larvae by 82% since April 2015.[19] While engineered mosquitoes can reduce the need for harmful chemical spraying (Guarino 2016), uncertainty remains. Effects on mosquito numbers around the release area are not well understood, nor what happens when release stops. Could there be long-term ecosystem effects? Could the gene transfer to other species, or the design evolve out (Scott et al. 2016)? Will 80-90% population reduction be sufficient when trials are scaled up (LaFrance 2016)?

Friendly™ mosquitoes are a short-term fix that could help with a dire problem that affects the least advantaged. But it is solutionist: it frames the problem around the organisms, ignoring the complex economic and social picture. Better is equated with synthetic biology, not eradicating Zika, which might prioritise mitigating poverty and inequality.[20] At the 2013 synthetic biology/conservation meeting, Oxitec's co-founder, scientist Luke Alphey, defended general concerns around solutionism: describing a project as a "panacea" would be as "hubristic" as "to claim that these problems are so complex that no new technology could contribute to a solution" (Yong 2013).

16 At the time of writing, this paper reporting mutations (whose publication saw CRISPR companies' stock price fall) was under consideration by *Nature Methods* after being challenged.

17 Oxitec is a 2002 spin-off company from the University of Oxford.

18 Open field trials have taken place in Brazil, the Cayman Islands, Malaysia, and Panama.

19 As of 2016, the mosquitoes still did not have Brazilian commercial approval, but the trial received local funding. Oxitec's factory was breeding two million Friendly™ mosquitoes per week (Ferreira 2016).

20 Social solutions are vital weapons against mosquito spread (World Health Organization 2016). Mosquitoes breed in standing water (as little as a discarded bottle cap) and so are often more prevalent in neglected, poorer areas. The Piracicaba trial involved releasing three to four million mosquitoes per month to protect just 5,600 people; the local government estimated an annual cost of $7.50 per person, shifted from other methods (Ferreira 2016).

Zika brought synthetic biology positive publicity, but this better still faced resistance over unknown consequences and commercial interests.[21] A Florida Keys trial for Friendly™ mosquitoes, approved by the US Food and Drug Administration in August 2016, was resisted locally (Grens 2016), later passing in a non-binding referendum (Oxitec 2016b).[22] Oxitec invested heavily in community engagement; approval will open the $14bn US pest control market to GM insects (B. Schmidt 2016).[23] The UK has endorsed modified insects too: the House of Lords Science and Technology Select Committee (2015) concluded that "There is a moral duty to test the potential of the technology", whilst emphasising its importance for the UK economy. Social policy experts Jack Stilgoe and Sarah Hartley (2015), witnesses for the report, judged it as "moral blackmail", promoting the interests of "UK plc"(industry), and focused on promises made about the technology while avoiding scientific uncertainty. I agree: our focus must be on balancing whose better is served by a commercial technology that can temporarily suppress a species.

Bettering Nature

The Friendly™ mosquito embodies two potentially conflicting meanings of better, humanitarian and economic. But neither is better for the mosquito. Can better include non-humans? When synthetic biologists and conservationists convened in Cambridge, four years after Oxitec began field trials, Drew Endy told *Nature*: "How are we going to explore the notion that we might aspire to rework our civilization such that it dances better with the planet? The synthetic biology community, whatever the hell that is, isn't going to figure it out by itself" (Callaway 2013). The attendees discussed whether synthetic biologists could make nature better, engineering organisms for bioremediation (cleaning up earlier technologies), ocean acidification, tackling invasive species and pathogens, defaunation (Redford 1992; Dirzo et al. 2014), or ameliorating two billion hectares of degraded land.[24] Ecologist Stewart Brand—now an influential advocate for genetic engineering—even argued for de-extinction, the "revival" of lost species.[25]

What might the "wilds" look like if this future came to pass? I delved into this emerging imaginary through my critical fiction *Designing for the Sixth Extinction*.[26] Extrapolating the

21 Visibility can be problematic: science journalist Frank Swain spotted conflicting headlines on the *Daily Mail's MailOnline* website, published within days of each other. On 19 January 2016, one asked: "Are GM mosquitoes the key to wiping out the Zika virus? Brazil set to use engineered bugs to eradicate 'brain-shrinking' disease" (Woollaston 2016). On 31 January, a second headline asked: "Are scientists to blame for Zika virus? Researchers released genetically modified mosquitoes into Brazil three years ago" (Curtis 2016).

22 The referendum was the same day as the US election that saw Trump elected.

23 Potentially worth $400m to Intrexon, according to Schmidt (2016).

24 Bioremediation is a long-promised application of synthetic biology (e.g. Singh et al. 2011).

25 Brand (2009) has shifted towards "eco-pragmatism". He believes that resurrecting creatures could ignite public interest in ecology, promoting "prudent" biotechnology as a "Green tool" to pessimistic environmentalists (Rich 2014). In 2011, his Long Now Foundation (co-founded by Brand in 1996) established the "Revive & Restore" (2016) project to pursue de-extinction. Brand persuaded George Church to help bring back passenger pigeons, alongside Church's efforts to resurrect woolly mammoths and Neanderthals. With their habitats lost, enthusiasts imagine mammoths helping to rewild landscapes. De-extinction is criticised as solutionist, reducing the impetus to modify human behaviour yet diverting funding from "real" conservation (Monbiot 2013a). For more on de-extinction, see Sherkow and Greely (2013), and Shapiro (2015).

26 The work was commissioned for "Grow Your Own..." (2013-14) at Science Gallery Dublin.

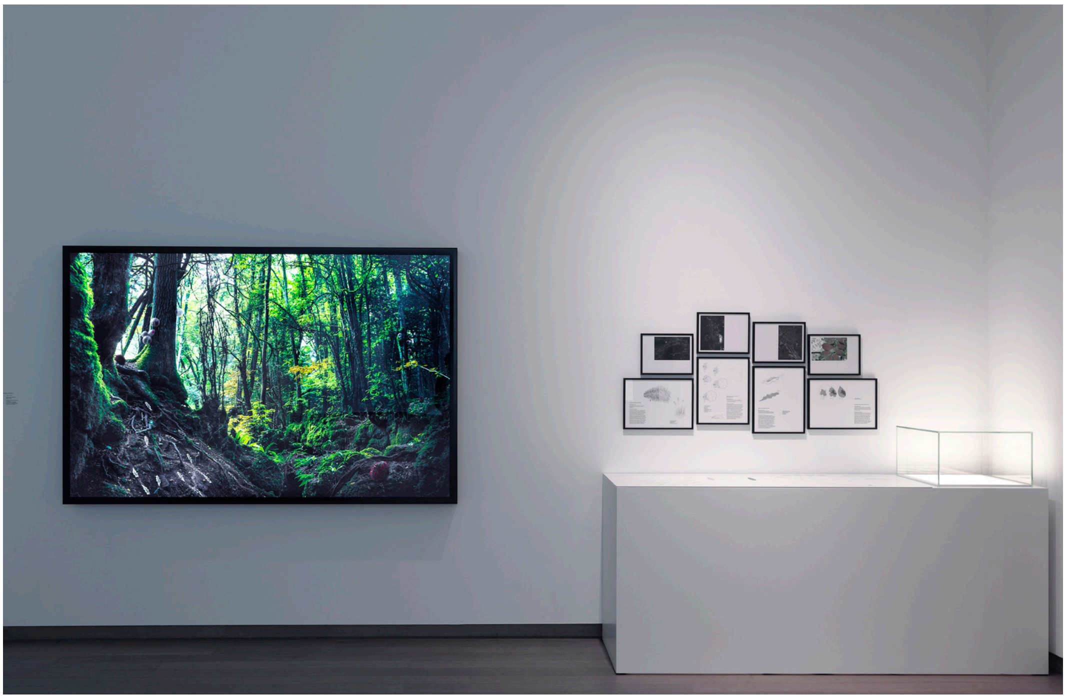


Figure 4.3
Installation view of the 2015 light-box version of *Designing for the Sixth Extinction* (2013-15) at “What Design Can Do”, Stedelijk Museum, Amsterdam, 2015.

momentary convergence of these groups into a future, I wanted to yield new perspectives on policy and research choices being made now, some by visionaries in that room.[27]

The work centres on a large framed photograph, 225cm wide by 150cm high, which appears like a window from the gallery into a perfect, verdant forest (figure 4.3). Closer inspection reveals strange organisms lurking in the undergrowth (figure 4.4). In the fiction, synthetic biodiversity, commissioned and financed by corporate interests, has been let loose to "rewild" nature.[28] These "ecological props" would be designed to support endangered natural species and ecosystems, replacing vanished organisms, or protecting existing ones from pathogens or pollutants. I described them as biological devices, detailed only through the instrumental language of patent texts and diagrams. Living only to preserve nature, would these machines even be alive? If nature were totally industrialised for the benefit of society—for some synthetic biologists, a logical endpoint of synthetic biology—would nature still exist for us to save?[29] Using synthetic biology to make nature might "erode" our very understanding of it, a concern raised by the conference's convenors (Redford et al. 2013, p.2).

To design the organisms and the synthetic ecosystem they operated within, I consulted with synthetic biologists and conservationists, including conference organiser, conservationist Kent Redford, threading together existing ecological policy like rewilding and "biodiversity offsetting" with synthetic biology research (see Appendix E).[30] These insights helped me to flesh out an imagined world of economic, scientific, social, and policy practices that would shape biological products (figure 4.5). I was not proposing this as a likely, desirable or undesirable future: I wanted to look at how a future is built from past and present choices. Using design critically to intervene in history (Dilnot 2015) reminds us that imaginaries are constructed, and thus "other worlds are always there for the making" (Jasanoff 2015b, p.339).

In the studio, my assistant Gemma Lord and I identified four ecological problems affecting UK forests. We imagined ourselves within the fiction as future biodesigners drawing up specifications for remedial devices. While the project was rooted in current scientific discussion, we delved into unreality, playfully collecting "features" from across the living kingdoms and inventing new ones. We passed our blueprints as technical line drawings and material references to the computer artists, who modelled the devices and then placed them into photographs we took in a forest so lush it looked unreal.

27 The United Nations' Secretariat of the Convention on Biological Diversity's (2011) *Nagoya Protocol* set out guidelines for sharing genetic resources to limit bioprospecting and exploitation. After consultation it published a second report looking at synthetic biology's impacts on existing biodiversity and regulation issues (2015). The Seventh International Meeting on Synthetic Biology (SB7.0), the 2017 iteration of the field's agenda-defining conference series, included a conservation session.

28 For more on rewilding, a real conservation strategy that reintroduces keystone species to restore natural ecosystems, see Monbiot (2013b).

29 "Novel ecosystems" are ecosystems built, modified or engineered by humans, without natural counterpart. See Hobbs and Higgs (2013).

30 Biodiversity offsetting is a controversial market-based conservation mechanism, used in the US and Australia, and piloted in the UK between 2012 and 2014. It involves offsetting biodiversity loss in one location by delivering the same amount elsewhere, e.g. by improving another site to compensate for developing greenfield land (Department for Environment, Food & Rural Affairs 2013).

Figure 4.4
"Rewilding with Synthetic Biology" (2013) from *Designing for the Sixth Extinction* (2013-15). The exhibited image is 225cm wide by 150cm.

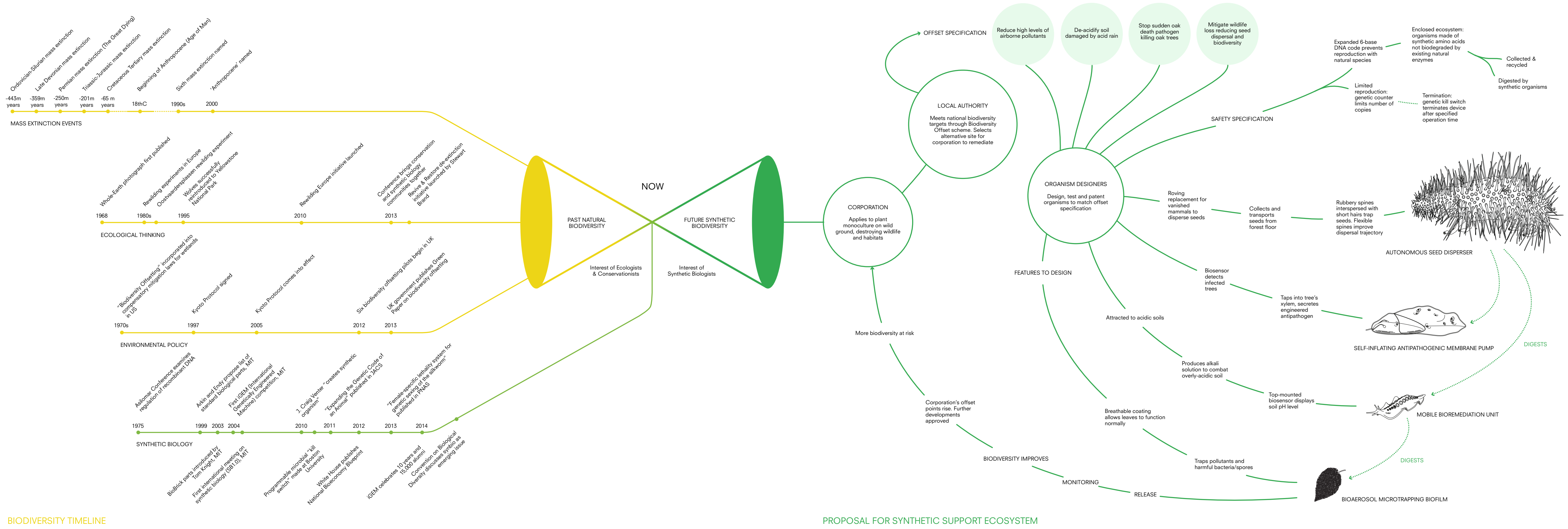


Figure 4.5
"Timeline for a Synthetic Ecosystem", commissioned in 2014, shows the research and imagined system behind *Designing for the Sixth Extinction*. The left half shows real past events, policy and research choices feeding into the present debate, from which I extrapolate a future that might come to pass. The right half details the institutions and policies that support the imagined "synthetic ecosystem".

The "Self-Inflating Antipathogenic Membrane Pump" (figures 4.6-7) is a fungus-like machine that would self-activate to inject serum to protect trees affected by sudden oak death, a real global threat currently without cure.[31] The slug-like "Mobile Bioremediation Unit" (figures 4.8-9) would secrete slime to neutralise soils made acidic by pollution. The "Bioaerosol Microtrapping Biofilm" (figure 4.10-11) is a self-replicating biological film that would collect pollutants and viruses.[32] The large "Autonomous Seed Disperser" would collect and disperse seeds in its wiry and rubbery spines (figure 4.12-13). Standing in for disappeared mammals, it would solve the diminished biodiversity of the "empty forest".[33]

The complexity of these devices is stretched to the edges of plausibility—and beyond—but they contain scientific ideas tethered to the present, recognisable to synthetic biologists. The "patent" texts reference biosafety measures in development, including cell replication counters (e.g. Friedland et al. 2009) and genetic kill switches that limit the devices' lifespan (e.g. Chan et al. 2015). The devices operate using a DNA system enlarged beyond the four existing bases, ATCG. Real efforts to make "unnatural" biology include changing or adding new letters to the DNA code, and expanding what it can encode for (e.g. Greiss & Chin 2011; Lajoie et al. 2013; Malyshev et al. 2014; Y. Zhang et al. 2017).[34] Scientists speculate that this could allow biology to make new, useful products, or be better controlled when released, if designed to be incompatible with natural DNA (e.g. Rovner et al. 2015).[35] "Xenobiology" pioneer Steven Benner believes a cell could run on an entirely different code (Callaway 2014). Expanding DNA is a "mechanism for greater biological diversity, and thus potentially for building a better biological future", enthusiasts proclaim (Thyer & Ellefson 2014).

But would an alternative DNA code make the machines "synthetic" in an unexpected way? Could the novel amino acids and proteins encoded for result in new, non-biodegradable materials, which no enzyme had yet evolved to digest? SynbiCITE synthetic biologist Tom Ellis agreed with my speculative logic. I decided that the devices would be designed to consume each other, cleaning up after themselves, with this closed technological ecosystem the result of decades of negotiation around biosafety.

31 Sudden oak death, visible through lesions in the tree's bark (called bleeding cankers), is caused by a fungus-like pathogen, *Phytophthora ramorum*, distributed in mist or air currents. It has decimated some North American oak populations. Strains have appeared in the UK, currently affecting larch and Douglas fir trees (Forestry Commission 2017).

32 Biofilms, like the plaque on your teeth, are collectives of microorganisms that stick to each other, and usually to a surface, as they produce a sticky matrix.

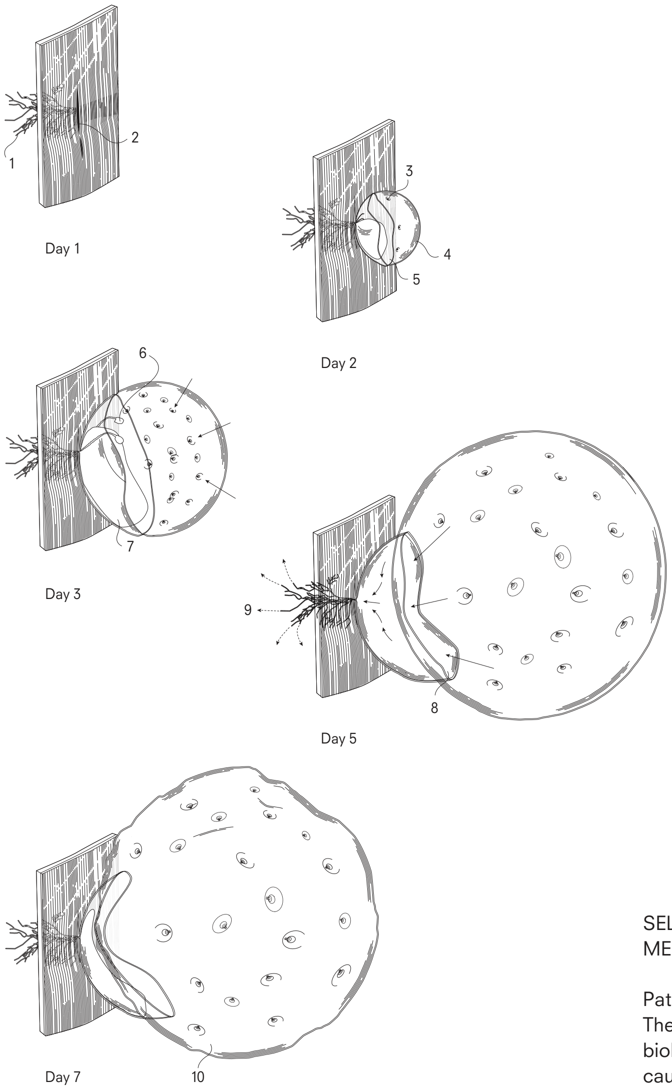
33 An "empty forest" looks healthy and intact, but defaunation—the loss of key organisms—impacts on the biodiversity of other species, including plants (Redford 1992).

34 There is a range of approaches to making synthetic life. Protocell scientists try to make life from its chemical constituents, to understand better how life emerged (e.g. Lentini et al. 2017). For a summary of these "bottom up" approaches, see Jewett and Forster (2010) and Rasmussen (2009). At the time of writing, synthetic life "from scratch" has not yet been created. J. Craig Venter boasted in 2010 that his team had made "the first self-replicating species we've had on the planet whose parent is a computer" (Gibson et al. 2010; Wade 2010), but "Sc1.0" was an existing organism with a synthesised natural genome inserted (Pennisi 2010). A "minimal" organism with a streamlined genome could offer a controllable "chassis" to make useful products more easily (Hutchison et al. 2016). Scarab Genomics branded their 2002 attempt to make a "Clean Genome" *E. coli* as "Less is Better and safer" (Church 2012, p.7). For more on synthetic life, see Calvert (2010).

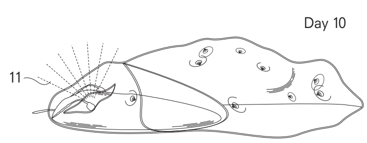
35 For arguments for xenobiology, see Schmidt (2010).

Figure 4.6
“Self-Inflating Antipathogenic Membrane Pump” (2013). Computer renderings based on “technical” drawings were superimposed onto photographs; these specimen close-ups accompanied the main forest scene.

Figure 4.7 (RIGHT)
“Self-Inflating Antipathogenic Membrane Pump Patent” drawing (2013-15). At GYO (2013-14), the patent drawings, texts, and close-up photographs were printed and mounted individually (see Appendix G). I later united drawings and texts, and framed them (see figure 4.3).



1. Pathogen-detecting network
2. Canker on infected oak
3. Non-return air valves
4. Balloon pump
5. Membrane
6. Spore producers
7. Antipathogenic serum reservoir
8. Pressure differential reached
9. Serum injecting
10. Deflation prior to decoupling
11. Spore release



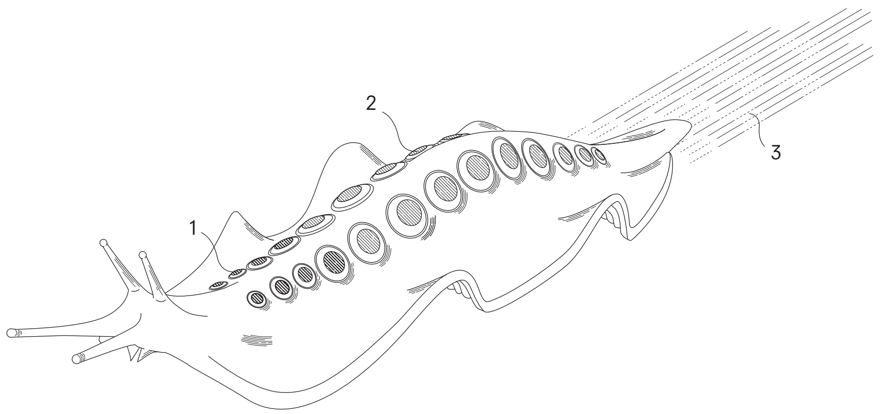
SELF-INFLATING ANTIPATHOGENIC MEMBRANE PUMP

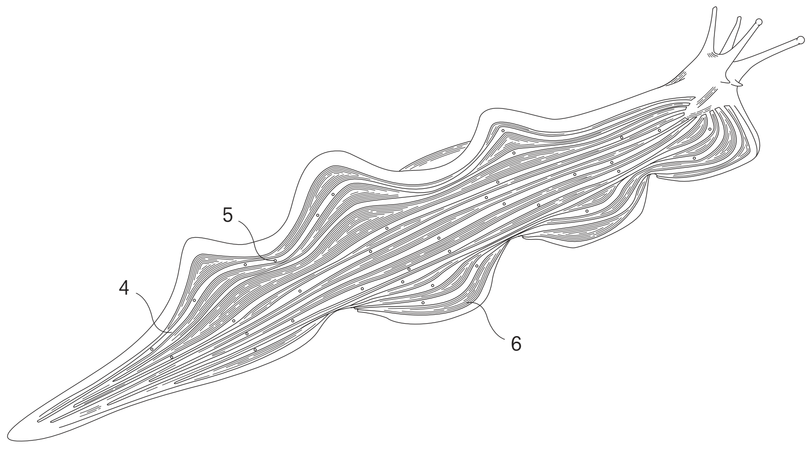
Patent Background
The present invention relates to a synthetic biological device used to treat the infection that causes Sudden Oak Death.

Statement of Invention
The single-use device is distributed via spores to establish filamentous networks within oak trees. A biochemical sensor activates the dormant network on detection of infection. A two-part diaphragm pump self-assembles with an inner and outer chamber. The self-inflating outer chamber surface is distributed with non-return valves to permit the ingress of air. The inner chamber produces an antipathogenic serum. At full inflation, the membrane pump pushes serum into the infection site. Post-injection, the pump deflates, decouples, and spores are released. The device operates using a 6-base DNA code that produces synthetic materials, to prevent ingestion by natural organisms. Biological waste is managed by the Autonomous Seed Disperser.

Figure 4.8
“Mobile Bioremediation Unit”
(2013).

Figure 4.9 (RIGHT)
“Mobile Bioremediation Unit
Patent” drawing (2013-15).





MOBILE BIOREMEDIATION UNIT

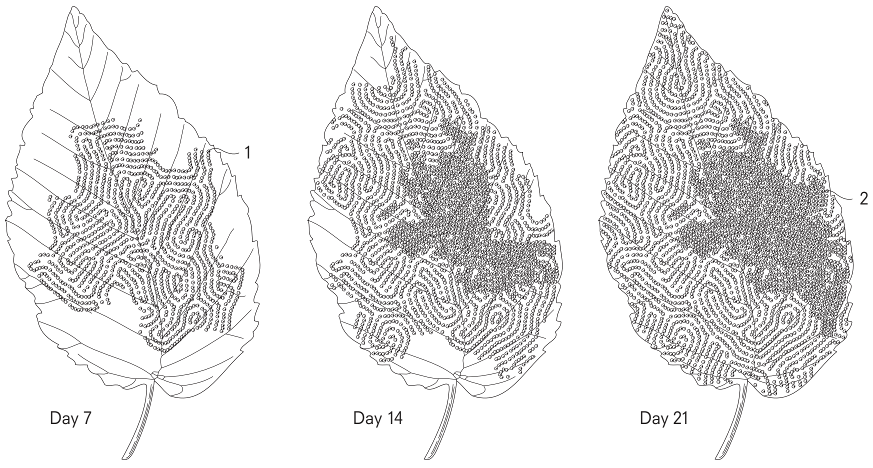
Patent Background
The present invention relates to a biologically-powered mobile soil bioremediation device with pH sensing and display capabilities.

Statement of Invention
The device is a soil bioremediation unit that neutralises high soil acid levels caused by pollution. The chassis is designed to disturb the topsoil as it moves. Outlets on its lower surface disperse an alkali hygroscopic fluid. Distributed pH sensors are linked to colour-changing display nodes on the upper surface, which switch from yellow to red in acidic pH areas. The device is programmed to move towards acid soils. Designed with two extra bases in its DNA, it is indigestible to natural biodiversity to promote biosafety and prevent horizontal gene transfer. The unit can produce up to ten copies. A genetic killswitch limits the device to a twenty-eight day functional lifespan.

1. Display node (red - acid)
2. Display node (yellow - alkali)
3. Alkali hygroscopic fluid
4. Soil agitator ridges
5. pH sensors
6. Fluid outlets

Figure 4.10
“Bioaerosol Microtrapping
Biofilm” (2013).

Figure 4.11 (RIGHT)
“Bioaerosol Microtrapping
Biofilm Patent” drawing
(2013-15).



1. Biofilm colonisation
2. Bioaerosol particle trapping

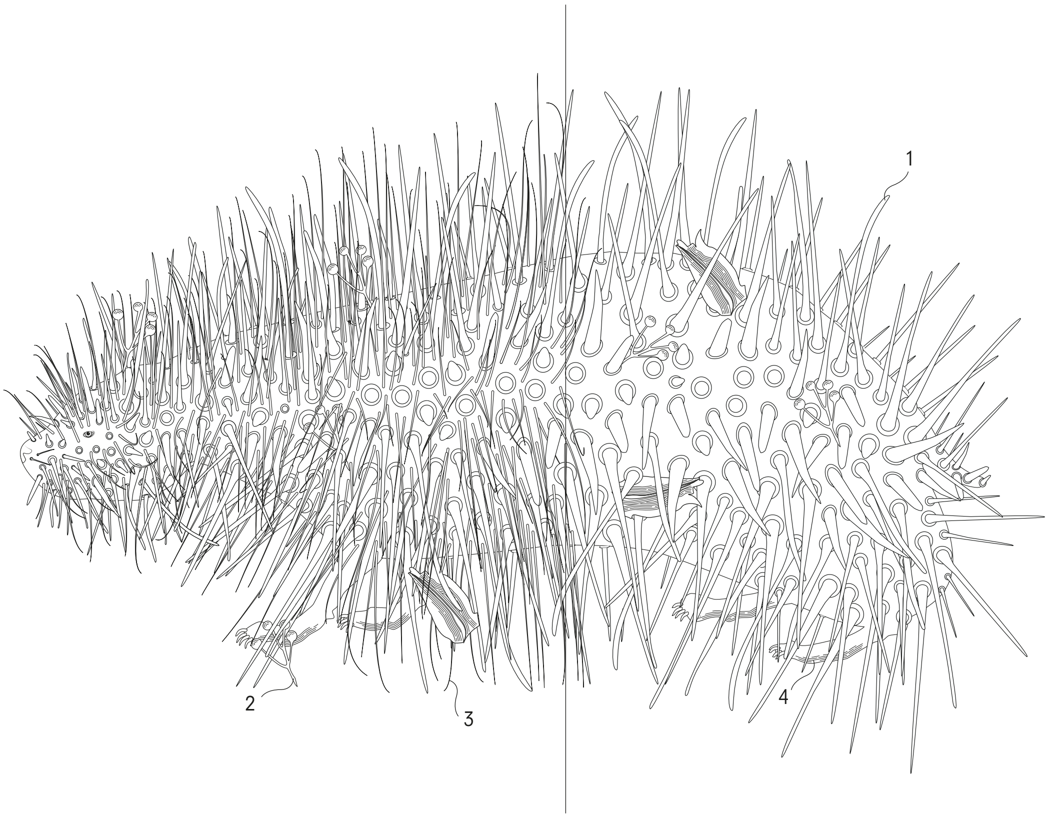
BIOAEROSOL MICROTRAPPING BIOFILM

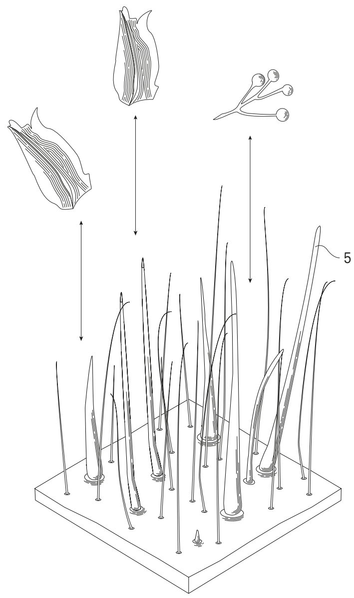
Patent Background
The present invention relates to a self-replicating biofilm that traps airborne pollutants and harmful biological matter including virus particles, bacteria and fungal spores.

Statement of Invention
The self-replicating biofilm coats leaf surfaces to provide maximum surface area to trap and secure harmful airborne particles that cause damage to biodiversity, e.g. Chalara fraxinea fungal spores responsible for ash dieback. The underlying leaf surface continues to function normally due to regular spacing between the biofilm nodes. Any trapped matter is safely discarded with the leaf when it is shedded by the tree in autumn. This biowaste is collected and processed by the Mobile Bioremediation Unit as part of the 6-base DNA closed synthetic ecosystem technology.

Figure 4.12
“Autonomous Seed
Disperser” (2013).

Figure 4.13 (RIGHT)
“Autonomous Seed Disperser
Patent” drawing” (2013-15).





AUTONOMOUS SEED DISPERSER

Patent Background
The present invention relates to a roving seed dispersal device that increases local plant biodiversity.

Statement of Invention
The autonomous device has a specially designed surface that collects and disperses seeds from local plant species. The precision distribution of coarse hairs interspersed with flexible rubberised spines enables maximum aggregation and distribution. The movement of the chassis induces flexing of the spines to release collected seeds, which are then pressed into the soil. The device is programmed using a 6-base DNA code that builds the chassis out of inedible synthetic proteins to prevent consumption by natural species. Power is generated by waste processing of other synthetic devices including Mobile Bioremediation Units. Reproduction is programmed to 5 copies per unit, and lifespan limited via killswitch to 600 days.

1. Flexible rubberised spines
2. Spines sweep up seeds
3. Seed-trapping hairs
4. Seed tramplers
5. Spines relax to release seeds

After the project's first exhibition in October 2013, a potentially troubling new technology was announced that, unlike Oxitec's species suppression, could permanently recompose wild species and ecosystems. Genes generally have a 50% chance of being inherited by an offspring; some have evolved a way to improve their odds of inheritance by appearing on a chromosome where previously they did not. Using CRISPR, Church and Kevin Esvelt, a postdoctoral fellow in his laboratory, showed that a gene could be "driven" through a sexually reproducing species over a small number of generations, with a copy passing from parent to every offspring (Esvelt et al. 2014). "Gene drives" could confer a gene for malaria resistance on an entire population of mosquitoes, or eliminate it entirely (A. Hammond et al. 2015).

"A release anywhere is likely a release everywhere", Esvelt explained (Specter 2017). Recognising the need for public engagement, the science was published with a policy paper (Oye et al. 2014), and an explanatory guest post on *Scientific American* (Esvelt, Church, et al. 2014). "The important thing is to actually listen to the public's concerns. And then try to visualize things that can go wrong and think of ways to guard against them", Church told *Popular Science* (Interlandi 2015). In anticipation, they proposed a technique to reverse gene drives (DiCarlo et al. 2015), while Esvelt explored "daisy-chain" systems that self-limit after a number of generations (Noble et al. 2016). That invention is explicitly presented as a way to "simplify decision-making and promote ethical use by enabling local communities to decide whether, when, and how to alter local ecosystems". Synthetic biologists are designing biology embedded with presumptions of others' betters.

Gene drives are not covered by existing regulation, and would make national boundaries meaningless. In 2016, the US National Academies concluded that "highly-controlled field trials could proceed" (US NASEM 2016, p.166). Even Esvelt was critical of their report, telling *The New York Times* that this fundamentally misunderstood the technology's power (Harmon 2016). There are many unknowns: suppressing one population could shift problems to new vectors, genes could transfer into wild species, or the intentional extinction of species could unintentionally throw ecosystems out. The ETC Group's Jim Thomas (2016) thought the report failed to scrutinise commercial or military interests, suggesting the United Nations govern the technology.[36]

Sixth Extinction highlights that this future is not necessarily better, but contingent on the dreams and choices of actors involved. This reflects reality: in January 2016 Esvelt moved to MIT's Media Lab to head a new Sculpting Evolution group. His work now involves very public efforts to promote open research and emphasise its risks. Advocating transparency, safeguards, and "community-responsive science", he is approaching communities early (MIT Media Lab 2015). Esvelt (2016) went to Martha's Vineyard to "introduce the idea of releasing mice", engineered not to spread Lyme disease. "Education alone will not do it [...]. You have to show that you understand their concerns", since "trust is not a given. It must be earned each and every time". He admitted being disappointed when the Martha's Vineyard audience agreed to progress, hoping for one "skeptic" to challenge the project.

36 Jim Thomas notes that Esvelt and Smidler's (2015) patent, filed by Harvard University, lists weeds that could be controlled, making it of commercial interest.

Lyme disease can be devastating, but should residents of an exclusive holiday island decide what is better for our shared nature? Can a scientist lead an unbiased engagement process, abandoning his invention if rejected? However well intentioned, the release of designed organisms is irreversible and synthetic biodiversity won't be contained within portions of nature. As Thomas observed, synthetic biologists originally promised the technology would be secure in the lab, then that its release would be limited through biosafety measures; now, not only would it "survive in the wild—it is intended to take over in the wild" (Specter 2017). *Sixth Extinction* frames the diverse betters such systems might try to serve, from the market to conservation, revealing a complicated picture that may be far from better. As synthetic biologists seek to make nature better, we must differentiate what is really better for nature—which, as Chapter 2 explained, eschews optimisation—and what is better, for which of us.[37]

Modernising Nature

Imagining that humans can solve nature's problems by lessening our impact on it, or by changing, eliminating or bettering it, implies that humans are separate from nature; nature is the problem, not us. *Sixth Extinction* made visible this belief that pervades synthetic biology, itself rooted in positivist, moralising, and solutionist ideas familiar to modernist design (Ginsberg 2014a, p.57). Like the modernists, synthetic biologists position themselves as designers who can determine what's best for us. Chapter 1 showed how design's embrace of the modernist fictional optimum has led us to isolate designs from context, with disastrous effects. Synthetic biologists' enthusiasm to follow suit is concerning. Endy (2016, Appendix H, p.248) sees change afoot: "for me, synthetic biology is in the middle of a transition from enabling us to live on earth, to enabling us to live with earth, where we don't change human nature, but we change humanity's relationship with nature". But this reflects his evolving vision, not the mainstream imaginary with its dreams of modernising nature.

A different vanguard can offer insight here. In 2015, a group of academics, environmentalists, and members of Californian pro-technology environmental think tank the Breakthrough Institute (BTI), including "eco-pragmatist" Stewart Brand, launched a manifesto, *Ecomodernism* (Asafu-Adjaye et al. 2015). They argued that the "good, or even great, Anthropocene" they sought required "decoupling" humanity from nature, not harmonising with it. Since "nature unused is nature spared" (2015, p.19), we should intensify our impact on smaller chunks of it through urbanisation, centralising land ownership, economic modernisation, and technological advance.

Critics saw a proposal for top-down control dictated by a few, steeped in nineteenth-century values, poised to deliver a better future only to the post-industrial urban elite.[38] As *Sixth Extinction's* biotechnological fixes also show, the idea of coupling saving nature to saving capitalism fails to interrogate the project of modernity itself and its delivery of unequal futures

37 Philosopher Joachim Boldt (2013) has explored whether it is humanity's moral obligation to synthesise organisms to improve biodiversity, concluding that it is not.

38 For arguments against Ecomodernism, see Isenhour (2016), Smaje (2015a; 2015b), Monbiot (2015b), and Latour (2015).

(Smaje 2015a).[39] Modernity liberated us from our local ecosystems (Harari 2015, p.392), but we were never ruptured from nature, we entangled ourselves in it (Latour 1993; Dilnot 2015, p.192).[40]

Synthetic biologists necessarily view biology as separable from "nature" and its processes (see Chapter 2), but some also imagine humans as separable from nature. Esvelt has described natural selection as "heinously immoral" in its savagery; humans "no longer need to be governed by nature" (Specter 2017).[41] Perhaps "nature"—which conservationists worried that synthetic biology might erode our understanding of—is part of the problem, blocking us from making it better.

Many thinkers have wrestled with humanity's role in nature. Hegel saw man as a product not just of nature, but of society and history, whose use of science and technology enabled the "mastery and transformation" of his natural environment (see Fukuyama 1989, p.4). Philosopher and sociologist of science Bruno Latour (1993; 2009) has described nature as a metaphysical and also political category. Philosopher Timothy Morton (2007) challenges the construct itself, referencing Romantic literature and art's emphasis on "nature" as a separate spectacle. Nature is not just good-looking bits of wilderness, like *Sixth Extinction* offers, but the entire planet, including us: we can't decouple from it. For Morton, cultural separation is a barrier to productive ecological thinking.

Nature may not exist, but ecologies and ecosystems do. The *Fundamentals of Ecology* (Odum 1953) shifted many scientists' study of nature from discrete organisms to a metaphor of a machine functioning through interlinked balanced and harmonious ecosystems. In the 1960s, this cybernetic concept fuelled a growing environmentalist movement, with Brand at its forefront. Scientists then moved from equilibrium to an "ecology of chaos" (Worster 1990), where prediction within a complex system was all but impossible.[42] Morton (2010; 2016) suggests that we should better see ourselves enmeshed or living in co-existence with these complex ecosystems.[43]

The environment is intrinsic to our long-term well-being. Megan Palmer (2016), co-director with Endy of Synberc's Practices Thrust, explains the thrust's focus, asking: "Does getting better at engineering biology necessarily increase our thriving, our security, our economic prosperity, or might it imperil it?" Evaluating whether engineering biology makes things better means

39 Modernism has released many from poverty and subjugation, but it has subjected many to the same forces. Life expectancy has gone up, but mostly because of reduced infant mortality, not because we all live longer lives. Its critics argue that more of the same will not deliver something different (Smaje 2015a; Monbiot 2015b).

40 The Ecomodernists cite a "spiritual" attachment to nature as reason to protect it. "Even if a fully synthetic world were possible, many of us might still choose to continue to live more coupled with nature than human sustenance and technologies require" (Asafu-Adjaye et al. 2015, p.25).

41 In a clarifying blog post on that report, Esvelt (2017) describes nature as "amoral", but still defends his position: now we have the power to intervene and eradicate species, the decision whether to do so becomes a moral one for society.

42 What meteorologist Edward Lorenz (1972) called the "butterfly effect". For more on the science of chaos, see Gleick (1987).

43 At WISB, I hoped to explore the possibility of synthetic biology envisioned though this paradigm, rather than technological modernism and optimisation (see Chapter 2).

asking how it benefits the planet. The UK's Royal Society (2012) decrees that well-administered technology will determine our future survival. But, operating within the complex systems we are part of, synthetic biology can only offer the pretence of modernist control. Like design, it should reconsider its modernist influences.

4.3 Conclusions

"Who gets to imagine the future with science and technology?" Sheila Jasanoff (2009, p.28) asked international policymakers and synthetic biologists at the U.S. National Academies. These three chapters have shown the architecture of synthetic biology's dreams of better to be in the hands of a few scientists and engineers. Their speculation has yielded a very real technoscience, presenting us radical, co-existing, and diverging visions of better futures, embedded in freezers of biological parts, vats of vanilla flavour, and free-flying engineered mosquitoes. Although biology has proved to be more complex than the engineers expected, and humans may never fully control it, technological advances are leaving policymakers scrambling as it becomes ever more possible to change ourselves, eliminate species, or invent new ones.[44]

Synthetic biology is rooted in dreams of better: the belief that humans can make biology better, and that a better biology will better our world and even ourselves. Like mainstream design, it is optimistic, persuading us that optimising biology can deliver the optimum.

These chapters delved into the construction of synthetic biology's imaginaries to address my questions about what its vanguards mean by better, how those betters are shaped, by whom, and to which values. Originating in commercial, modernist, scientistic, solutionist, or techno-utopian mindsets, I have shown that as these ideologies are embedded and globally extended, better is unlikely to be delivered to all. Imaginaries obfuscate the very real environmental and social issues that synthetic biology presents. Resistance has emerged, but synthetic biologists admonish critique as denying others a better future, which they determine. But better depends on needs, beliefs, and context: there is no one better for all people and the planet. My critical fiction *Sixth Extinction* identified this problem, eliciting a troubling blend of ecological and economic betters. As we choose which technologies to pursue—from DIYbio to life extension funded by Silicon Valley billionaires—what better means needs societal discussion.[45] Transparency is essential.

These chapters illustrated my use of critical design techniques to elicit synthetic biology's troubles. Chapter 1 explained that SCD sometimes shields the designers' concerns to elicit the audiences'. But if *Sixth Extinction* doesn't make my views on better clear, it isn't an effort to mask my troubles: the project's function is to identify them. In the next two chapters I further examine my projects, their impact, and their relationship with bettering.

Synthetic biologists make political choices as they imagine futures. As Latour (2015) reminded the Ecomodernists, politics is not arbitrated by a moral good, it is the stories that we fight for. We use politics to change the world, but we need stories to reimagine that world (Jasanoff 2015b, p.339). The final chapters examine design's troubled efforts to engage critically with synthetic biology, its imaginaries, and the imagination of alternatives.

44 Mushrooms engineered not to brown have avoided regulation, as CRISPR was used to delete genes, not add them (Waltz 2016). "Micropigs" developed as model organisms were at one point to be sold as pets by China's premier genomic research centre (Larson 2015). In 2015, human germline editing was only subject to debate *after* Chinese scientists announced they had edited human embryos (Callaway 2016).

45 For discussion on societal deliberation on science and technology, see Feyerabend (1978) and Callon et al. (2009).

Chapter 5. Critically Designing Biology

5.1 Introduction

I was trying to explain synthetic biology's possible futures to Jony Ive, Apple's celebrated chief of design, and it wasn't going well. Ive was touring our Royal College of Art 2009 graduation show, and had stopped in front of *Growth Assembly*, my collaboration with Sascha Pohflepp. Using the convention of botanical illustration, our work critically imagined a future where engineered plants replace industrial standards with softness and diversity (figure 5.1). "One day, we might grow products inside plants", I breezily told a bemused Ive.[1]

I soon found better ways to introduce my experimental critical design work in synthetic biology to new audiences. I began using the provocation that synthetic biologists want to transform biology—and with it, life—into a twenty-first-century design discipline. I'm curious about what synthetic biologists will design, who decides what is good design, and if synthetic biologists become designers, what will designers do?

Since then, biology, design, and technology have rapidly entwined. In 2012 I went to the trendsetting digital technology festival South by South West Interactive (SXSW) with synthetic biologists Jason Kelly, co-founder of start-up Ginkgo Bioworks, Christina Agapakis, and Patrick Boyle. We were all new to SXSW, as was our proposed panel's subject, "Designing Living Things". From the stage, we looked across the empty ballroom to see crowds overflowing from next door, where Joi Ito, director of MIT's Media Lab, was introducing their latest silicon-based technology. Just three years later, Ito's 2015 SXSW session was called "Synthetic Biology: Learn, Do, and Dream", and the Media Lab's festival programme was devoted to synthetic biology, with the main festival featuring at least six synthetic biology panels.[2] In 2016, there were eleven. The idea that biological engineering was "design" had entered the mainstream, with technology magazine *WIRED* declaring, "Move Over, Jony Ive—Biologists Are the Next Rock Star Designers" (Stinson 2015). *WIRED's* feature connected Ginkgo's organism designers with Apple's established design culture, but it also referenced my critical interventions, Synthetic Aesthetics and *Designing for the Sixth Extinction*. Their inclusion in synthetic biology's burgeoning design culture hinted at a more complex entangling.

1 I was repeating a remark made by plant synthetic biologist Jim Haseloff in his lab at the University of Cambridge, which inspired our project (see Ginsberg 2014b, pp.101-7).

2 The SXSW 2015 Media Lab lounge events featured design curator Paola Antonelli, science fiction author Bruce Sterling, and bioeconomist Rob Carlson. For more on synthetic biology's growth at SXSW, see Biohacking Safari's account (Largeteau 2015). Later in 2015, Ito hired Kevin Esvelt to lead a new Sculpting Evolution group (see Chapter 4), adding to the Media Lab's existing optigenetics Synthetic Neurobiology group, controlling brain cells using light and genes.

Figure 5.1
Installation view of *Growth Assembly* (2009) by Alexandra Daisy Ginsberg and Sascha Pohflepp.

Synthetic biology's arrival on the mainstream technology scene is not just a sign of progress. And the biology/design consilience is not just enthusiasm for designing things with biology. It is a voguish merging of the imaginaries described in the preceding chapters that tell us that design, biology, and technology each make things better. Since sociotechnical imaginaries are visions of desirable futures that become embedded in cultures and institutions and are extended globally, producing real effects, any shift to making technology from biology is not just a material change. It is ideological, and raises unprecedented ecological, ethical, and societal questions. Just because we can design biology, should we? Who decides? So far, critical design and art have contributed to making a space for much-needed technological critique. Rather than dealing with "better" directly, this chapter examines these efforts to engage critically with synthetic biology's imaginaries of bettering biology, the world, and nature itself.

As this chapter shows, the artists and designers doing this work—myself included—approach synthetic biology with diverse intentions and techniques.[3] Within a single project, critical self-initiated research, commercial commission, and public engagement can blur. Critique can be optimistic, useful, and even instrumental, "bettering" synthetic biology; fiction and material realism can co-exist (figure 5.2). Creating a space for critique is not without its troubles. Critique can be rejected; conversely, artists and critical designers inescapably contribute to synthetic biology's imaginaries by making its promised future more tangible. Still, social scientists have admired the impact of this tangibility on a technoscience that often resists critique (Calvert & Schyfter 2017).[4] Synthetic biologists are now looking to our languages and practices to advance their visions and ease in a new "consumer bio" space. As we mutually colonise and perpetuate each other's imaginaries, the resulting biological design platform could be troublesome for critical design's future. Whose better does it serve?

This chapter examines this complex situation by looking at critical design's work in, on, and with synthetic biology in the public realm, science, and industry. I look to the trouble that critical designs can provoke, exposing the workings of the sociotechnical imaginary even as they manipulate, exploit, and participate in it. My broad definition of critical design includes projects that engage in what philosopher Alfred Nordmann (2010) poetically describes as a "forensics of wishing".[5] Analysing my and others' project, I start by mapping out the mutual colonisation between synthetic biology and critical design. Next, I examine how negotiating realism can affect a work's critical success. Finally, I address how critical design's position relative to the imaginary impacts on it. Rather than placing society and critique downstream of the technoscience, I argue that using design to reframe synthetic biology as a product of society could maintain critical spaces.

3 This chapter is not a comprehensive survey of bio-art and biodesign. Since art and design's engagement with synthetic biology is relatively recent, I include relevant works that examine other biotechnologies.

4 Calvert and Schyfter (2017) recognise a shared desire between STS and art and design practices for critique and "opening up" (Stirling 2008). Admiring art and design for its experimentation, playfulness, and making of tangible artefacts with greater impact than academic papers, they suggest working together to develop an "emergent form of critique".

5 A forensics of wishing allows us to investigate the dreams that shape technologies. Nordmann proposes this method to help technology assessment (TA) take a critical stance, rather than its evolution into a technoscience itself, which simply responds to other technoscience. The approach is informed by the "Collingridge dilemma": a technology cannot be fully assessed until it is in use, when change becomes difficult (Collingridge 1980).

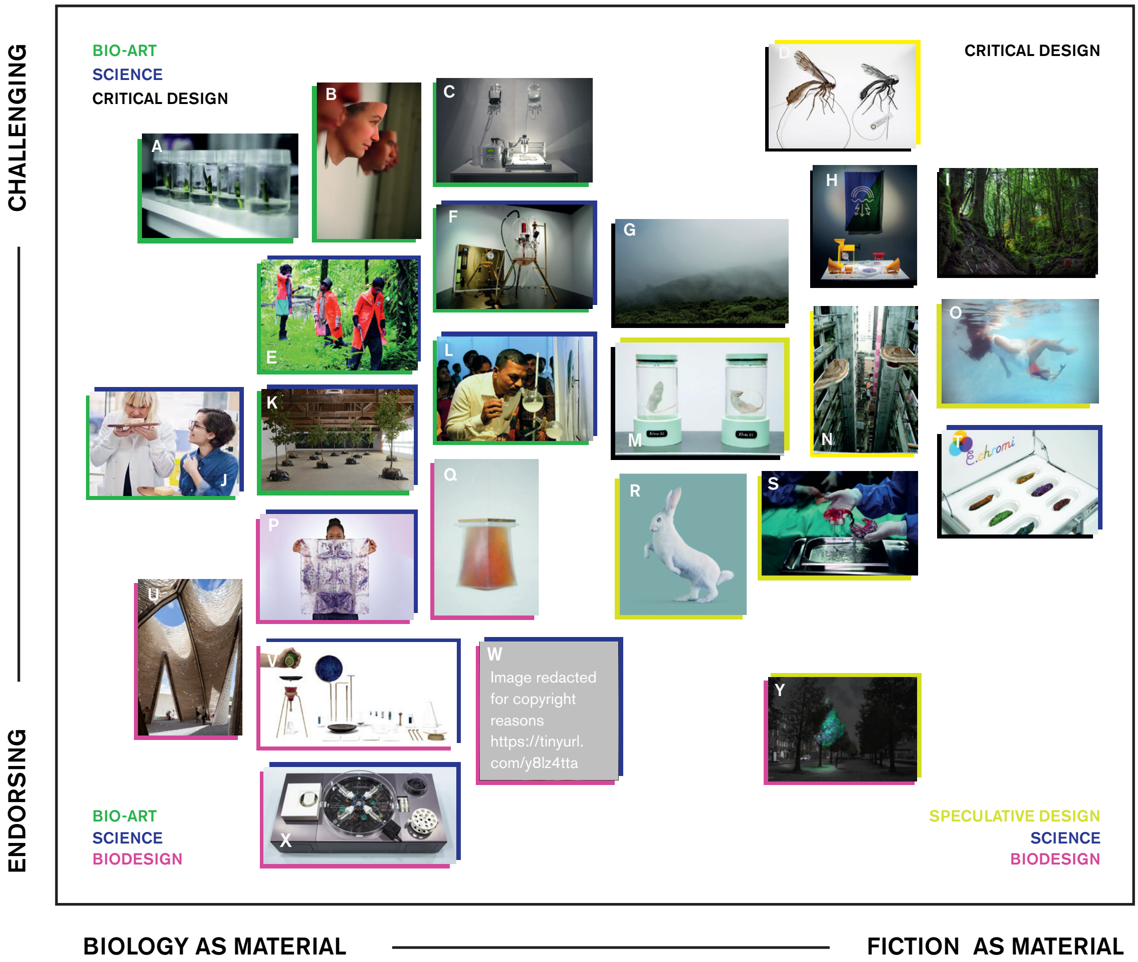


Figure 5.2
Artists and designers approach biology with diverse intentions and techniques. Mapping the works featured in the "Grow Your Own…" exhibition at Science Gallery Dublin (2013-14), with additional examples, shows how classifying work as bio-art or biodesign is not straightforward. Works can challenge the technology, endorse it, or do both. Practitioners can use biology or fiction as their material, or combine the two. They can focus on the material itself, or on ideas and cultures surrounding it, or both. Collaborations between art, design, and science further blur categorisation.

A. In *Common Flowers/Flower Commons* (2008), BCL (Shiho Fukuhara and Georg Tremmel) clone commercially available GM carnations to explore real intellectual property issues.

B. *Stranger Visions* (2013) by Heather Dewey-Hagborg challenges "genohype" using real biological material: found samples of DNA are turned into 3D printed portraits that approximate the appearance of the samples' owners, based on just a few testable traits.

C. *The Mechanism of Life—After Stéphane Leduc* (2013) by Oron Catts, Ionat Zurr, and Corrie Van Sice uses chemistry to make basic "protocells", challenging the hype surrounding visions of synthesising life.

D. *Into Your Hands Are They Delivered* (2013) by Tobias Revell speculates on a dystopian future where modified mosquitoes infect the world's oil supply.

E. *Teen Gene Poem* (2009-2013) by (Art) ScienceBLR included work from Srishti Institute of Art, Design and Technology's iGEM teams. Each year, students used biological material and narrative for poetic and critical ends, such as synthesising the "smell" of rain.

F. *The Great Work of the Metal Lover* (2012) by Adam Brown, in collaboration with Kazem Kashefi, uses living extremophiles (microorganisms) to deposit gold, exploring imaginaries of perfecting nature.

G. *Zero Park* (2013) by Sascha Pohflepp depicts a fictitious landscape that appears natural but is secretly used to grow rocket fuel, questioning the bioeconomy.

H. *The New Weathermen* (2013) by David Benqué critically speculates on a fictional group of environmental activists using GMOs as a tool to fight power.

I. *Designing for the Sixth Extinction* (2013-15) uses fiction to examine synthetic biologists' imaginary of bettering nature to save it.

J. For *Selfmade* (2013), Christina Agapakis and Sissel Tolaas made cheese from the human microbiome, a concept developed during their Synthetic Aesthetics residency. The "microbial portraits" both challenge and promote biological materials, raising cultural questions.

K. For *Blighted by Kenning* (2011), Charlotte Jarvis worked with scientists to encode the Universal Declaration of Human Rights into bacterial DNA, extract it, and contaminate apples with it, exploring both the material and ideas around it.

L. *Banana Bacteria* (2011) by Howard Boland uses BioBricks designed by the MIT iGEM 2006 team to make bacteria that smell like bananas. Appropriating a scientific application into a cultural one is intended to spark discussion.

M. *All That I Am* (2011) by Koby Barhad blends reality and fiction to explore real regulatory issues, speculating on the implications of cloning mouse models of Elvis.

N. *New Mumbai* (2012) by Tobias Revell is a utopian speculative fiction, imagining energy-generating giant mushrooms grown in urban environments.

O. *I Wanna Deliver a Dolphin* (2011-13) by Ai Hasegawa is a critical speculative fiction that explores how, faced with rising human populations, women could choose to gestate dolphins.

P. *Faber Futures: The Rhizosphere Pigment Lab* (2012-) by Natsai Audrey Chieza, in collaboration with Professor John Ward, is a material research project experimenting with the use of soil bacteria to print textiles.

Q. *Xylinium Cones* (2013) by Stefan Schwabe and Jannis Hülsen develops new methods for growing bacterial cellulose in three-dimensional forms.

R. *Post Natural History* (2012) by Vincent Fournier is a speculative art project that imagines a future archive of engineered organisms, exploring human intervention in evolution.

S. *Circumventive Organs* (2013) by Agatha Haines speculates on future designer organs, questioning biotechnology's potential role in our bodies.

T. *E. chromi Scatalog* (2009) by Alexandra Daisy Ginsberg and James King, with the University of Cambridge iGEM 2009 team, is a speculative fiction extrapolating real science for critical debate.

V. The "Grow Your Ink" workshop (2013) by Marie-Sarah Adenis with La Paillasse, Paris, allowed workshop participants to make ink grown by bacteria. The project is now a start-up company, PILI.

Additional Examples

U. *Hy-Fi* (2014) by David Benjamin/ The Living. A temporary tower built from Ecovative's mushroom bricks at MoMA PS1, New York, NY, celebrates the use of biological materials.

W. *Wanderers: An Astrobiological Exploration* (2014) by Neri Oxman et al. mixes fiction with biological and 3D printing technologies to imagine clothing for future space travellers.

X. Microbial Design Studio (2017) by Biorealize makes synthetic biology accessible for non-experts through the design of a tool to facilitate genetic engineering.

Y. "Glowing Nature" (2014) by Studio Roosegaarde unquestioningly speculates on an imagined future where glowing trees are used as streetlights.

5.2 Colonising Imaginaries

The growing involvement of artists and designers in synthetic biology has sparked a reciprocal interest in our techniques for public engagement, innovation, and to some extent, critical enquiry. This colonisation of each other's dreams of better offers opportunities, but the emerging biological design platform is serving economic bettering, potentially overshadowing the space for "dialogue and dissent" we have built (Ginsberg et al. 2014 p.xviii).[6]

The simplest manifestation of this is the appropriation of ideas. Speculating on products, even critically, can load those products with potential. In 2009, the University of Cambridge iGEM team engineered bacteria to secrete different pigments, which they called *E. chromi*. Designer James King and I developed a workshop for the students to consider the implications of their invention. One provocation we suggested was a disease monitoring system, available in 2039 as a probiotic yoghurt containing bacteria engineered to detect chemical markers of different diseases in the gut. Any signal would trigger pigment production—and coloured faeces. Taking a briefcase containing model poo to iGEM 2009 (figure 5.3), King and I used humour to challenge synthetic biologists' predilection for engineering metaphors like cogs and circuits that obscure biology's messy, living materiality (Ginsberg 2009; 2014b, pp.123-5). Our critique penetrated synthetic biology's cultural imaginary: although synthetic biology visionary Tom Knight told *New Scientist* it was the craziest idea out of iGEM (Coghlan 2012), synthetic biologists started describing our fiction as a goal.[7] In 2014, Harvard scientists Jonathan Kotula et al. (2014) programmed bacteria and fed them to mice to detect and record a chemical signal in their guts, measurable in (non-coloured) faeces.[8] The Defense Advanced Research Projects Agency (DARPA) funded that work in a call to protect American intellectual property in an emerging global bioeconomy.[9] Kotula is now chief synthetic biologist at Synlogic, a medical start-up engineering the human gut microbiome. The conceptual link between our fiction and their invention shows how critique can be folded back into the culture it reflects on. Disturbingly, we may have contributed to a future of biological surveillance.

6 I use colonisation here as a spatial metaphor to describe the mutual appropriation of practices and imaginaries, and inform the navigation of these spaces and platforms. I am aware of the important discussions around colonialism and decolonising design; my use of it here is unconnected.

7 For example, I saw the Beijing Genomics Institute present our *Scatalog* as a research goal in a slide at The Fifth International Meeting on Synthetic Biology (SB5.0) at Stanford University in 2011.

8 The work was done at Pamela Silver's laboratory at Harvard University, where Christina Agapakis did her PhD. The *E. chromi Scatalog* was knowingly technically a bad idea: testing for more than one disease would produce a brown-coloured signal, and the amount of bacteria required to produce visible colour signals in faeces may itself cause illness; fluorescence would be a better marker. Our more fundamental question—whether a bacteria's design would be stable in the gut—*is* being addressed. In May 2017, Silver's team showed their engineered bacteria functioning for six months in the mouse gut as "live diagnostics of inflammation" (Riglar et al. 2017). I declined *New Scientist*'s request to use the *Scatalog* to illustrate their report on that work ("Gene tweak in gut bacteria could turn faeces blue if you're ill") to avoid further entangling (Wilson 2017). Our provocation that suggested it would only be culturally acceptable in 2039 is yet to be seen.

9 DARPA's (2011) Chronicle of Lineage Indicative of Origins (CLIO) grant also sought ways to detect designed biology in people, for biosafety reasons. *WIRED* equated it to Microsoft Word's "Track Changes" option (Venkataramanan 2011).

Figure 5.3
The *E. chromi Scatalog* (2009) by Alexandra Daisy Ginsberg and James King, with the University of Cambridge iGEM 2009 team, was designed to take to iGEM to initiate discussion.

Recognising design's power to imagine and communicate, some synthetic biologists are adopting its practices. After synthetic biologist Reid Williams collaborated with the design consultancy IDEO during his Synthetic Aesthetics residency, he left the laboratory to train as a designer at IDEO.[10] Meanwhile, Christina Agapakis (2011) included her Synthetic Aesthetics collaboration with smell artist Sissel Tolaas in her science PhD.[11] In 2014, she experimentally programmed Cultured Products, a session for Ginkgo at iGEM. Echoing my suspicion that desire, not need, could popularise GMOs, the talks transformed synthetic biology into an aesthetic concern, showcasing luxuries like alcohol, coffee, and perfume.[12] In 2015, Agapakis formally joined Ginkgo in the novel role of Creative Director, where she pioneers sophisticated ways to improve genetic engineering's image. She appropriates the strategies of cultural discourse from Synthetic Aesthetics for marketing: for example, recreating the smell of extinct flowers based on DNA from flowers preserved in the nineteenth century (Brouillette 2016). But her remit also includes finding ways to "complicate our understanding between biology and our social relationships", opening up more nuanced spaces for consideration (Agapakis 2016). Ginkgo's stand at the 2016 World Perfumery Congress trade show included a table scented with Tolaas's body odour.[13] Critical design has been appropriated for commercial profit, albeit used by one industry to challenge another.[14]

The term "biodesign" encapsulates this mutual colonisation. In 2016, the UK's Synthetic Biology Leadership Council (SBLC) refreshed the *Synthetic Biology Roadmap* (see Chapter 3), rebranding it *Biodesign for the Bioeconomy* (SBLC 2016). The updated national strategic plan is intended to accelerate the commercial translation of this technoscience for economic benefit. Perhaps biodesign sounded more palatable for the "synbiophobia-phobic", as it seemed odd to adopt a term already used in bioengineering for medical device design (e.g. Zenios & Denend 2010). Design writer William Myers (2012) has also claimed that biodesign classifies work by artists, architects, designers, and bioengineers. Myers' survey promises a future of biological manufacturing, unquestioningly adopting synthetic biology's imaginary of sustainable abundance. Differentiating biodesign from biomimicry and ecological design, his biodesigners integrate living things in their work, or use organisms to make or process materials (2012, p.8).[15]

10 Wendell Lim and Reid Williams, both at Lim's laboratory at University of California, San Francisco were Synthetic Aesthetics residents. We paired them with IDEO designers Will Carey and Adam Reineck. Together, they looked at the design process itself (Lim et al. 2014, pp.169-180).

11 For their residency, Agapakis and Tolaas (2014, pp.271-282) made microbial portraits: cheese cultured using human body bacteria. During her synthetic biology postdoctoral research at University of California at Los Angeles, Agapakis taught at ArtCenter College for Design, Pasadena, CA, and wrote about science for general audiences.

12 For an account of the Cultured Products session, and Art and Design at iGEM 2014, see Jain (2014).

13 Reasoning that there is such thing as a "bad" smell, only interesting ones, Tolaas uses smell to challenge perceptions. Tolaas regularly works with industry. Her studio/laboratory is supported by International Flavours and Fragrance, a molecule manufacturer whose own efforts to make the world smell "better" by masking culturally bad smells is the target of her critique.

14 This effort has not gone unnoticed: in 2017, Agapakis was named by *WIRED* as one of "20 tech visionaries who are creating the future" (Wired Staff 2017).

15 Biomimicry imitates biological elements or systems in form or function (Benyus 1997). Ecological design includes "cradle-to-cradle" systems, mimicking nature's reuse of material (Braungart & McDonough 2002). In science and engineering, "biomaterials" describe engineered materials, biological or synthetic that interact with body tissues for medical use. Synthetic "bio-inspired materials" copy natural or living matter (e.g. metal actuators mimicking the movements of jellyfish). "Bio-based materials" like bioplastics are derived from living

Confusingly, he also includes critical projects that delve into biotechnology's aesthetics, ethics, or potential uses through artistic and speculative practice, including my own.[16] What is real, proof of concept, or fiction is not always clear, nor are the creators' intentions. This blurriness makes appropriating critical works for others' agendas easier.

Biodesigners must be wary of uncritically perpetuating others' imaginaries. At SXSW 2014, celebrated installation designer Daan Roosegaarde showed off a tobacco plant engineered to glow. He said he was working with the plant's inventors "to make a really large one of them like a tree which glows at night instead of standard street lighting", explaining that, "It will be incredibly fascinating to have these energy-neutral but at the same time very poetic landscapes" (Pallister 2014). A second project, "Glowing Nature", proposed softly glowing trees coated in "biological paint" (figure 5.4).[17] Roosegaarde's foray into genetic engineering ignored its much documented obstacles, presenting biology as just another technology to exploit.[18] This project promoted synthetic biologists' imaginaries of an easy-to-engineer biology that will better the world, and nature too.

Unlike Roosegaarde, architect David Benjamin (another Synthetic Aesthetics resident) and his studio The Living often work with biology (e.g. figure 5.2.U).[19] Still, Jonathan G. Wald (2016), an anthropologist studying the bioeconomy, notes how ideas of sustainable and localised adaptation in many of The Living's projects infer that biological processes "ought to, in their logic, create forms and structures on the spot that are better adjusted to their environment". For example, *Bio Computation* (Benjamin 2012) uses biologically-informed computation to design speculative biomaterials, which his accompanying film positions within a "carbon neutral" "glucose economy", itself a contested geopolitical ambition (*The Economist* 2009).[20] As Wald (2016, p.7)

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biology such as plants, and are more processed than "biological materials" like wood or leather.

16 Artistic and speculative critical projects feature in both Myers' *Bio Design* and his follow-up, *Bio Art*, where he claims that only bio-art, not biodesign, deals with ambiguity (2015 p.7). In *Bio Art*, Myers broadens what has been seen as a niche practice (e.g. Sharpe 2016), including in it mainstream artists who deal with biology. I agree that the subject is more important than the material, but disagree with his inclusion of ambiguous, critical projects in an intentionally instrumental definition of biodesign.

17 Roosegaarde is famous for transforming existing technologies into public installations, often using light for dramatic effect.

18 Glowing plants are a recurring meme. In 2013, a crowdfunding campaign for "Glowing Plants: Natural Lighting with No Electricity" raised $484,013 from 8,433 backers on Kickstarter. George Church endorsed it, saying: "Even a weakly glowing flower would be a great icon" (A. Evans 2013). With global media coverage, the project triggered much debate around GMO release. In 2017, Evans admitted the science had proved more difficult than anticipated, terminating the Kickstarter to focus on a fragrant moss venture (A. Evans 2017). Roosegaarde named his plant's inventor and collaborator as scientist Alexander Krichevsky of State University of New York, Stony Brook, once part of Glowing Plant. Krichevsky started Bioglow (now Gleaux) to continue his plant work (Regalado 2016c). Gleaux appears to have plants available for order. Still, *Dezeen* clarified that Roosegaarde's "tree" would be an installation of smaller plants, noting that EU regulations restrict his use of the material now (Pallister 2014). At the time of writing, the tree has not materialised. Glowing microorganisms are an easier prospect: Roosegaarde is trying to incorporate them into a permanent installation on the Dutch Icoon Afsluitdijk. Glowee, a French start-up, is also promoting living lighting using microorganisms, with backing from French infrastructure company EDF. But maintaining any living biological infrastructure may prove extremely challenging.

19 David Benjamin and plant scientist Fernan Federici (2014, pp.143-154) were paired Synthetic Aesthetics residents. In 2014, San Francisco-based software giant Autodesk, who have a strong interest in facilitating the design of biology, bought The Living (Upbin 2014).

20 The film shows an animated globe with US energy reliance shifting from Middle Eastern oil to South

notes, biodesign is "planning for a world that does not yet exist". "Glowing Nature" and *Bio Computation* accept synthetic biology's imaginaries, serving someone else's better.

Some practitioners use speculative design to actively help realise others' dreams. Medic turned architectural visionary Rachel Armstrong (2012) invents chemical and biological fictions—often with scientists— that "precede" science. *Future Venice,* published in *Nature*, proposes propping up the sinking city on a protocell "reef" (figure 5.5) (Armstrong & Spiller 2010). Debating together, I realised our very different use of imagined futures: Armstrong describes her fictional protocells as a "probabilistic" technology (van Lier 2014). "These are prototype tests, it is not a formal technology. But we could see something within 10 to 20 years if this is something that the city of Venice wants", she explains (Hobson 2014a). For Armstrong, the technology depends not on scientific possibility, but on our desire and actions to make it real; failure to better nature will be the fault of those obstructing both progress and its vanguards.

New creative roles in industrial biotechnology now extend to the laboratory. In 2016, designer Amy Congdon became Senior Materials Designer at Modern Meadow, a Brooklyn start-up that recently pivoted from developing *in vitro* meat to making "leather" from collagen produced by engineered yeast. Modern Meadow's Chief Creative Officer, fashion designer Suzanne Lee, is turning the company towards design.[21] In 2014, Lee launched Biofabricate with the slogan "Design, Biology, Technology: Growing a Better Future".[22] She curates this industry conference with the work of artists, designers, scientists, and engineers. Tapping into the imaginary of sustainable abundance, Biofabricate (2015; 2016) aims to kick-start a future where "consumer products are designed and grown". Biofabricate is emblematic of the mutual colonisation: in 2016, the morning session was devoted to critical practice; the afternoon to industry. Can critique survive as synthetic biology's imaginaries of better are appropriated by design, and design's by synthetic biology, all to serve industry?

More traditional industries are aligning themselves with artists and designers experimenting with this new technology; proximity to the cutting edge reflects an aura of innovation (see Wilkes 2016). In a groundbreaking public use of GMOs for a major fashion label, Gucci commissioned critical designer Sputniko! (AKA Hiromi Ozaki) to produce a glowing dress for its gallery (figure 5.6).[23] She collaborated with scientist Hideki Sezutsu, who creates fluorescing silk by injecting jellyfish or coral genes into silkworm eggs.[24] *Tranceflora - Amy's Glowing Silk* aestheticises synthetic biology's imaginary of bettering nature, without questioning its agenda or the ethics of using living matter. As late capitalism encourages increasingly elaborate experience-led marketing, critical design can be co-opted and recuperated as advertising, commodifying

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American sugar. This promise was repeated in media reports (e.g. Coren 2013).

21 Suzanne Lee (2011) is famous for her "Biocouture" project, popularising growing bacterial cellulose in her TED Talk.

22 In biomedical engineering, biofabrication is the automated production of cells and tissue.

23 Sputniko! is a Design Interactions graduate, and now heads the Design Fiction group at MIT's Media Lab, where she describes herself as an artist. A second silk project, *Red Silk of Fate - Tamaki's Crush* (2016) incorporates the technology in a pop sci-fi short film.

24 Sezetsu, based at Japan's National Institute of Agrobiological Sciences (NIAS), previously made a wedding dress with Japanese couture bridal designer Yumi Katsura (Iizuka et al. 2013).

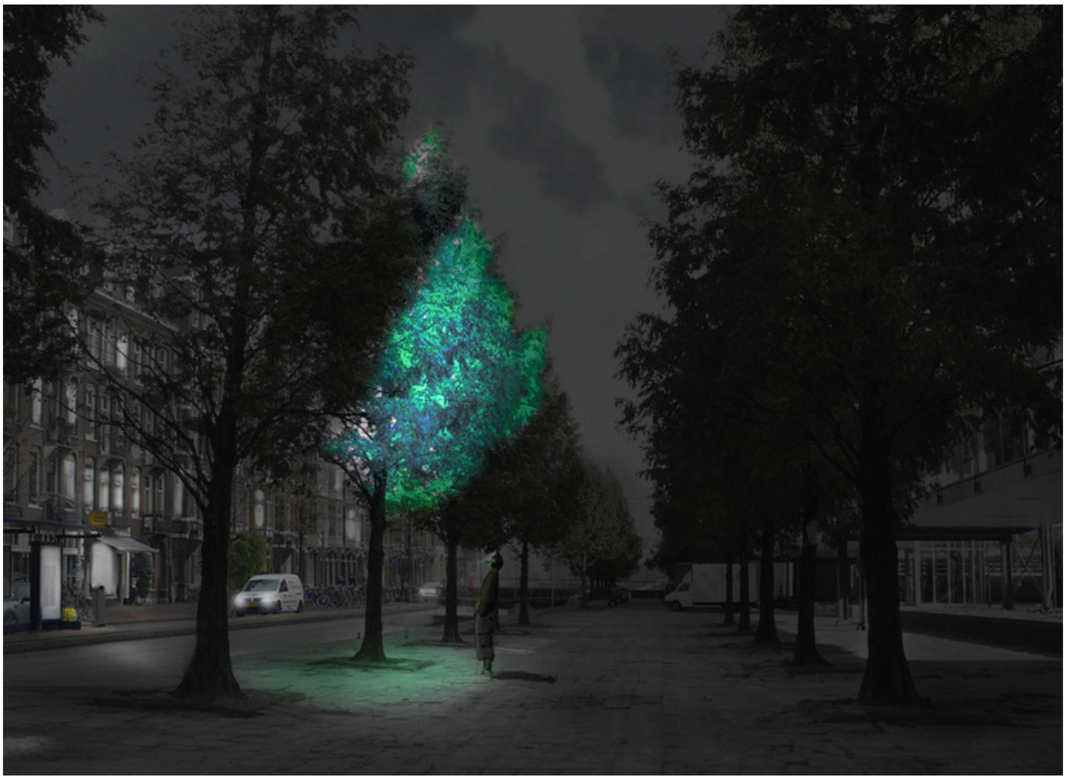

Figure 5.4
Studio Roosegaarde's "Glowing Nature" (2014) continues a meme of engineering trees to replace streetlights, without disscusing the technological or regulatory barriers.

Figure 5.5
Future Venice (2010-) by Rachel Armstrong and Neil Spiller proposes the engineering of protocell reefs to prop up a sinking Venice.

radical ideas into mainstream culture (see Pierce 2015, p.40). As Chapter 1 explained, Anthony Dunne (1997, p.75) saw critical design operating outside the market; this kind of advertising work may inure its critical potential.

Sportswear brands are taking an interest in synthetic biology's dreams of better, simultaneously bolstering biotechnology's image. Bolt Threads' engineered yeast is fed sugar from GM corn to produce a spider silk protein; this Engineered Silk™ is marketed as a high-performance material made from renewable raw materials.[25] Bolt has partnered with activewear brand Patagonia, while The North Face's Japanese distributors publicised their golden prototype MOON PARKA™ (figure 5.7), woven from Spiber Inc.'s *E. coli*-secreted spider silk. By contrast, when adidas launched their limited edition trainers made from AMSilk's Biosteel® spider silk at Biofabricate 2016 (figure 5.8) they made no mention of GMOs. adidas (2016) describe its Futurecraft Biofabric as "sustainable", made through a "fully natural process" . I warned them that this lack of transparency might trigger—not avoid—controversy (see Chapter 3).

Excited by this activity, European and US art and design schools are building laboratories to equip the next generation to participate in biotechnology.[26] But we should be wary of the appropriation of ideas and practices. Synthetic biology's vanguards have resisted social scientists' and NGOs' critique; now critical design is slipping into the service of economic bettering. The benefits brought by commercial funding, access, and exposure could neuter critique. Social scientists have admired critical design's playful, albeit troubled, engagement with synthetic biology, asking what social science could glean (Calvert & Schyfter 2017). But their experience in synthetic biology serves as a warning. Balmer et al. (2015) list the variety of difficult relationships that have emerged from being funded by synthetic biologists' grants, most memorably being cast as the "trophy wife". Investigating trends in interdisciplinary working between science and society, sociologists Andrew Barry et al. (2008) describe this "subordination-service" mode, in which one discipline serves another (often used to justify "art-science" projects).[27] In Chapters 2-4, I noted collaborative troubles in my practice. The troublesome stymied my WISB and iGEM projects, but still generated insight for practice. I agree with Barry et al.'s preference for "*inter*disciplinary autonomy" through a mode of "agonism-antagonism"; here opposition and critique can effect "radical shifts".[28]

Developing my own troublemaking/finding role for critical design within synthetic biology has required operating in a carefully negotiated space. As my work becomes more established, I feel freer to take a more adversarial stance within the field (see DiSalvo 2012). This "useful trouble" is critically optimistic, imagining that it could somehow better synthetic biology. But maintaining relationships and access to the architects of synthetic biology's dreams limits critique. Meanwhile, my work has undoubtedly paved the way for this proliferation of biodesign projects

25 In a heavily engineered media campaign, Bolt launched a competition at SXSW 2017 offering 50 winners the chance to buy a spider silk tie for $314.15 (Bourzac 2017).

26 For example, Design Academy Eindhoven and School of Visual Arts, NYC.

27 They also discuss a third "integrative-synthesis" mode, where partners work on an equal footing (Barry et al. 2008). Synthetic Aesthetics followed this to a point, as our residents spent two weeks in the laboratory and two weeks in the studio, working together to joint and independent agendas simultaneously.

28 For more on agonistic design practices, see DiSalvo (2010).

Figure 5.6
Tranceflora - Amy's Glowing Silk (2015) by Sputniko! This fiction was accompanied with a real Nishijin-Kimono dress made of transgenic glowing silk. The exhibition at Gucci Gallery, Tokyo, featured 3000 transgenic silkworm cocoons.

Figure 5.7
Prototype engineered spider silk MOON PARKA™ (2015), by Spiber Inc. in collaboration with GOLDWIN, The North Face's Japanese distributor.

Figure 5.8
The launch of adidas' Futurecraft Biosteel trainer at Biofabricate 2016, New York, NY, avoided mention of genetic engineering.

by designers, industry, and synthetic biologists, servicing synthetic biology's imaginaries. As critical design risks being absorbed into the imaginary, eliminating space for dissent, how can critical projects navigate this threat?

5.3 Navigating Realities and Imaginaries

Managing Imaginaries

Developing a successful "forensics of wishing" to trouble synthetic biology's dreams of better demands interaction with its imaginaries. But the appropriation underway shows that proximity can also trouble critical design. By conceptualising the imaginary as a designed space, we can consider how to navigate between it and realities, giving some control over critical work.

Some practitioners try to shield their technological critique from co-option by working strictly within the realms of scientific reality. Bio-artists Oron Catts and Ionat Zurr argue that material realism reduces hype and promotion of others' agendas.[29] Like biodesign, bio-art uses biological materials or organisms, and biotechnology's tools, but for "unusual or subversive" means (Kac 2007, p.18).[30] Bio-art generates shock and reflection by confronting us with the technology itself. Living artworks are unpredictable, affording them a powerful agency beyond the artists'. But this doesn't preclude their exploitation: Catts was happy when their tissue-cultured "jacket" on display at MoMA, New York, became infected, leading to a spectacular *New York Times* headline: "Museum Kills Live Exhibit" (Schwartz 2008). Still, the artists blame fiction for hype, not the ideas themselves, however radical.

In 2015, Catts and Zurr began using the language of design, framing their working prototypes as "contestable design" in opposition to speculative design's fictions (Montgomery 2015). Designed to look like a domestic kitchen appliance, *Stir Fly* (2016) is a bioreactor for growing insect tissue culture for food (figure 5.9). Its primary function, though, is to reduce hype. Suspended above the device, a bag of foetal calf serum (FCS) feeds the meat culture.[31] *In vitro* meat's pioneers often promote it as "victimless", promoting a future of sustainable abundance. But since no alternative to FCS yet exists, animals are just abstracted one step further from our plates. *Stir Fly's* design ensures the animals aren't hidden.

Contestable designs are reminiscent of "*chindogu*": designs that at first appear useful, but are amusingly "almost useless" (figure 5.10) (Kawakami 1995, p.8). Unlike *chindogu*, or non-optimal designs (see Chapter 1), contestable designs exclude ambiguity to communicate the artists' particular objection. They use humour, but the joke is on design: better is only possible without the design and the technology it enables. Contestable design critiques dreams of better,

29 Catts and Zurr produce work as The Tissue Culture and Art Project (TC&A). Catts was also a Synthetic Aesthetics resident.

30 For other bio-art approaches, see *Tactical Biopolitics* (da Costa & Philip 2008), for example.

31 Foetal calf serum is a blood product drained from unborn calves.

Figure 5.9
Stir Fly: The Nutrient Bug 1.0 (2016) by TC&A in collaboration with Robert Foster is a "contestable design". The prototype domestic appliance makes visible the foetal calf serum feeding "victimless meat", negating that imaginary. But its novelty inadvertently perpetuates the technology.

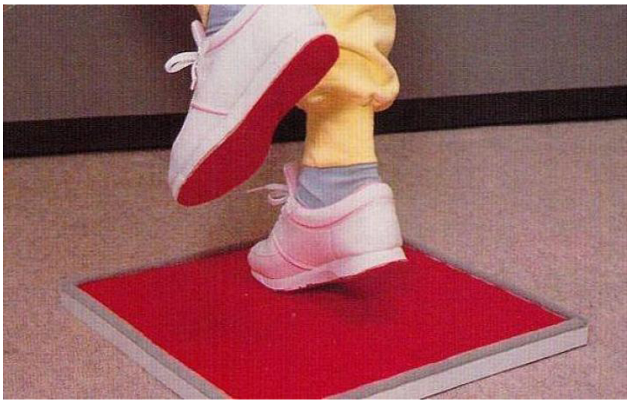

Figure 5.10
The Velcro Home Jogger is a classic "*chindogu*". Designed for everyday life, *chindogu* are intentionally anarchic, having "broken free from the chains of usefulness" (Kawakami 1995 p.125). *Chindogu* promise to make life better at first glance, but a closer look reveals our own longing to be bettered.

Figure 5.11
Screenshot of Koert van Mensvoort's *Rayfish Footwear* (2012) website, part of his hoax. Users could learn about the business and customise engineered rayfish-skin trainers.

yet offers little hope. If biodesign perpetuates imaginaries by taking promises at face value, paradoxically bio-art and contestable design *also* fuel imaginaries. The only innovation the artists encourage is the development of their protocols. Their primacy can be an act of resistance, but it can inadvertently progress the technology.[32] Once the shock wears off we may be desensitised, priming the technology for others' capitalisation. Staying with reality is not enough to avoid trouble.

Since imaginaries are designed fictions, fictions can be a valid medium for examining them: placing projects within the imaginary to question it. However, non-expert audiences may not know enough to identify what is real.[33] How much does the designer's responsibility then extend to the work's dissemination and consumption? Koert van Mensvoort stimulates discussion about technology and nature using design fictions.[34] *Rayfish Footwear* (2012), his hoax about a biotechnology company breeding designer stingrays for leather, even left some scientists uncertain as to what was real (figure 5.11).[35] *The In Vitro Meat Cookbook* is filled with recipes for lab-grown meat that "you cannot cook yet" (figure 5.12) (van Mensvoort 2014). It proposes *in vitro* meat as a possible "sustainable and animal-friendly alternative", but that "before we can decide whether we will ever be willing to consume in vitro meat, we must explore the new food cultures it may bring us" (van Mensvoort & Grievink 2014, p.7).[36] Framing aesthetics as the barrier to realisation, not the technoscience itself, is problematic.[37]

32 Cultured meat entrepreneurs have acknowledged that artists Catts and Zurr have primacy of the technology. For *Disembodied Cuisine*, TC&A (2003) grew frog skeletal muscle on a biopolymer scaffold. They cooked and served up the resulting tiny steak in a gallery performance, creating the "Semi-Living [as] the new class for exploitation".

33 Design researchers Coulton et al. (2016) discuss the challenges of designing plausibility in design fiction and signposting unethical deception. To ensure I'm investigating pertinent issues, my projects have plausible aspects, although I am less focused than them on making projects appear plausible.

34 van Mensvoort makes and disseminates his work through his Next Nature Network (2017). In 2010, the *E. chromi Scatalog* featured in the first stop of the touring "NANO Supermarket" exhibition he curated, filled with fictional nanotechnology "products", described as possible within the next 10 years. Since then, I've been more restrictive of others' framing of my work to try to avoid it being interpreted as a product proposal.

35 *MailOnline* reported *Rayfish* as real, but noted that David Edwards, Harvard University bioengineering professor (and biodesign enthusiast) told them: "You're right to question the claims. One suspects they are playing with genetics, if they are doing anything at all, and claiming an understanding they don't possess" (Fleming 2012).

36 *Dressing the Meat of Tomorrow* (2006), James King's very early Design Interactions student project, also explored the aesthetics of cultured meat. He used a more abstract language, advertising its arbitrary appearance to give the viewer space to imagine alternatives in a less didactic way.

37 *In vitro* meat is not synthetic biology, but the example is instructive. The *Cookbook* invokes "victimless" meat, promoting its sustainability by referring to "studies" that show it would emit up to 96% less greenhouse gases, but without citation (van Mensvoort & Grievink 2014, pp.12-13). The figures come from a speculative calculation that assumes large volumes of meat could be grown in bioreactors (which is far from current art), and that cultures would heat themselves, eliminating a significant likely energy cost (Tuomisto & Teixeira de Mattos 2011, p.6119). The *Cookbook* acknowledges the calculations use unproven cyanobacteria as the cells' feedstock. New Harvest (2016), a public charity that "strategically funds" the burgeoning "cellular agriculture" industry and "a post-animal bioeconomy", financed this research. The *Cookbook* also recognises New Harvest's support, and the study notes comments from *in vitro* meat pioneer Mark Post. Showing how hype spreads, the figures are often referenced without attribution to introduce *in vitro* meat, e.g. BBC News (2013) cited an "independent study" when reporting Post eating the first lab-grown hamburger. *The Guardian* repeated the figure, linking only to the BBC article (Gould 2014). I insisted on addressing these issues when van Mensvoort and I worked together on *Steak Shortie* (2015), a short film about *in vitro* meat commissioned for the *Knotty Objects* conference at MIT's Media Lab. Available at https://www.media.mit.edu/videos/knotty-objects-2015-07-16-04/.

Figure 5.12
Spread from *The In Vitro Meat Cookbook* by Koert van Mensvoort and Hendrik-Jan Grievink (2014 pp.114-115) showing a serving of fictional knitted meat.

Armstrong, van Mensvoort and I all design fictions in and around imaginaries, but our varying intentions may be imperceptible for the outsider: context affects realism. Unlike the *Rayfish* hoax, the *Cookbook* is described as a fiction for discussion: what Dunne and Raby (2008) call "design for debate".[38] But placing us inside the vanguard's imaginary while masking technical obstacles, his design blocks the non-expert from questioning the real issue: the visionaries' interests. Eating less meat is more likely to produce their greener future. Total control is impossible, but designers, curators, journalists, and critics have a role in designing deployment (see G. Russell 2017). Just as we learn to interpret and engage with other kinds of fictions, we need to guide audiences to parse critical designs, and consider the imaginaries they explore, and why.[39]

Aesthetic choices become an ethical issue. Critical designs that combine speculation and the language of products can inadvertently convince viewers that the future is here. Realism can immerse us in a fiction but, like bio-art's reality, it can desensitise us from dissent. Critical designers investigating future biological products can try to signify unreality through abstraction of objects and context (figure 5.1), or just context (figure 5.13), or objects (figure 5.14). In *Designing for the Sixth Extinction*, I particularly wanted to consider how biological "devices" might interact in context to stimulate discussion inside and outside the field (see Chapter 4). Since

38 For more on design for debate in the context of public engagement with science, see Caccavale (2014).

39 A lack of control may be part of the work, and avoids authoritarianism. Still, the designer can determine aesthetic choices, constitute audiences, and clarify intentions. They can also work with curators and press to define better the context for the work, and improve descriptions, press releases, and image choices.

Figure 5.13
Troika's *Plant Fiction: Selfeater (Agave autovora)* (2010) abstracts the background to signal the fictionality of this designed plant.

Figure 5.14
"Foragers 6" from *Between Reality and the Impossible* (2010) by Dunne and Raby contrasts unfamiliar objects against a familiar setting to communicate unreality.

Image redacted for copyright reasons
Available at: https://www.moma.org/collection/works/90063

Figure 5.15
Thomas Demand's *The Clearing* (2003). Demand's uncanny still lives are photographs of intricate paper models that simulate real life scenes.

I was essentially rendering the synthetic biologist's imaginary, I chose a hyperreal aesthetic to try to make the nature look *too* perfect to be real, inspired by Thomas Demand's ethereal photographs (figure 5.15). The device design was influenced by a flannel moth caterpillar, whose odd uniform appearance makes it object-like (figure 5.16).[40] I composed the large image like a traditional landscape painting to evoke the artifice of the cultural notion of "beauty", enhancing the strangeness of the machines infecting the scene (Lipps & Lupton 2015, p.228).

Some practitioners want to see empirical analysis of such works and their outcomes to improve "upstream" public engagement with science and technology (Kerridge 2015).[41] But this still puts design (and societal concerns) in the service of science. By definition, public engagement doesn't aim for acceptance of particular technologies, but my experience has been that acceptance is the expected outcome.[42] Empiricism also fails to capture critical design's unquantifiable effects. The designer's social contract may be optimistic, but design is not just a didactic, problem-solving endeavour, it is also an aesthetic activity, allowing the user to interpret and repurpose it for their needs. Critical designs reflect on *designing* itself; they use design to focus the "user" towards a particular enquiry. What "engagement" with that enquiry means depends on the enquiry, the context, and the audience; it can be philosophical or poetic. My concern is less to better synthetic biology's designs, more to encourage reflection on better.

In *Sixth Extinction*, I described living things as "machines" equipped with "kill switches". I wanted outsiders to be jarred by synthetic biology's use of instrumental language. The changed context also reminded synthetic biologists of the radicalness of their inventions. So I was pleased when non-experts were happily unsettled, like graphic designer Frith Kerr, who nominated it for "Designs of the Year 2015", describing it as "romantic, dangerous… and everything else that inspires us to change and question the world" (Design Museum 2015, p.88). While I had broken open the imaginary to reveal beliefs, tensions, and processes inside, Kerr was not taking it literally. But despite my choice not to simulate patent documents, for some, even the allusion to patents inferred reality. I had to clarify that I was using patent language as a tool to elicit unidentified questions (e.g. Schadwinkel 2016).[43]

The synthetic biology community had mixed reactions to *Sixth Extinction*. For some, the imagined public reaction was the problem, not the critique. The first presentation to synthetic biologists at WISB in November 2013 triggered the most heated debate I've had with the field.

40 This species enjoys fame for its resemblance to Donald Trump's hair.

41 Speculative designer, researcher, and former Design Interactions tutor Tobie Kerridge (2015) adopted more social scientific methods to question how to better curate and analyse project outcomes around speculative projects.

42 Public engagement (PE) is increasingly a priority for UK research councils to raise awareness, communicate research, share knowledge, and encourage dialogue about publicly funded science (EPSRC 2016). Shifting from the "public understanding of science" championed in the 1980s, PE describes a broad set of practices, analysed by Kerridge (2015 pp.69-91). Engagement with publics is an outcome of my work, e.g. GYO, but I actively distance myself from the term itself. Dunne and Raby suggested speculative design could be used for PE, but Kerridge argues that speculative critical design is not empirically proven to provide "downstream" public engagement.

43 For *Pure Human* (2016), design student Tina Gorjanc filed a real patent to speculatively make leather from Alexander McQueen's DNA, causing a media storm and confusion around what was real and what were her intentions (e.g. J. Jones 2016).

Figure 5.16
This flannel moth caterpillar (2013) inspired the design of the “devices”. Its lack of eyes and its uniform appearance make it more like an object than an organism.

Figure 5.17
Detail of glass model of *Tubularia indivisa* by Leopold and Rudolf Blaschka (1850s).

Barbara Gerratana of US funding agency the National Institutes of Health furiously argued that my speculation was irresponsible, and risked harming the field. In the museum, the context and scale of the work make its fictional nature clear. But I realised that in print or online the images looked more like reportage: I had circulated images of the work itself, not photographs of it framed. *Discovery News*' illustrated report announced that "Synthetic Creatures Could Save the Planet" (Staedter 2013), while science fiction website *io9* promised that "Synthetic Creatures Will Save the Planet" (Dvorsky 2013). Still, I was surprised when this coverage of my darkly titled critical fiction triggered an email from Kevin Costa, Synberc's manager, echoing Gerratana's concerns:

> As a card-carrying member of the research community, I love your inspired and thought-provoking work, but I also fret about how this message is heard by the general population. The graphic realism of the imagined organisms suggests that they are right around the corner, and lands on the far "hype" end of the half-pipe of doom (the quote from an anonymous scientist, "You're too close to reality," seems patently untrue to me). Do you worry about promising what the field can't deliver, or just scaring the public into an anti-GMO stance before we've had a chance to demonstrate the value of more basic applications? (Costa 2013).

io9 had quoted an unedited *Dezeen* interview in which I recounted a synthetic biologist, checking the work's veracity, observing the project might be "too close to reality", considering current discussions (see Fairs 2013). Still, *io9* had described the work as "conceptual" and "intended to spark debate"; its online commenters knowingly entered into the fiction.[44] And I wasn't promising that synthetic biology would save the planet, but reflecting on promises made by visionaries at the 2013 Cambridge synthetic biology/conservation meeting, many who were Synberc leaders (see Chapter 4). Clearly, manifesting the imaginary was revealing some of its mechanics. I realised I had not knowingly threatened the field's imaginaries before.

In 2014, I iterated the installation design to increase the fictionality. I combined the patent texts and drawings, framing them alongside the photographs to mark them more clearly as artworks, not evidence.[45] I collated my research into a timeline that mapped past factors that might trigger this future, where its imagined institutions were located (figure 4.5). Referencing natural history models (figure 5.17) and design prototypes, I 3D-printed a "Mobile Bioremediation Unit". In 2015, I showed four individualised models (figure 5.18) on a light box, where they seem to disappear from some angles, enhancing their unreality.[46] The large forest image was also displayed on a light box (figure 5.19).[47] Did this enhanced artifice reduce the project's radicalness? It was certainly more immersive, but viewers don't need literal representations to connect with work;

44 *io9*'s science fiction fan commenters got into the spirit of the debate. However, when my work was published in *Zeit Online* as part of a special on CRISPR, some commentators below the article felt impelled to defend the validity of my role to others (Schadwinkel 2016).

45 This new iteration was for "The Future is Not What it Used to Be", the Istanbul Design Biennial 2014, curated by Zoe Ryan and Meredith Carruthers.

46 With a larger starting budget I would have made a video work, and experimented with sound. For these later iterations, smell artist Sissel Tolaas and I discussed collaborating to imagine their smell; perhaps a pungent blend of plastic and soil fumes. I would still like to test the unreal aesthetics of the physical models further.

47 This new edition was commissioned for "Globale: Exo-Evolution", curated by Peter Weibel at ZKM | Center for Art and Media Karlsruhe, and "What Design Can Do" at the Stedelijk Museum, Amsterdam, both in 2015.

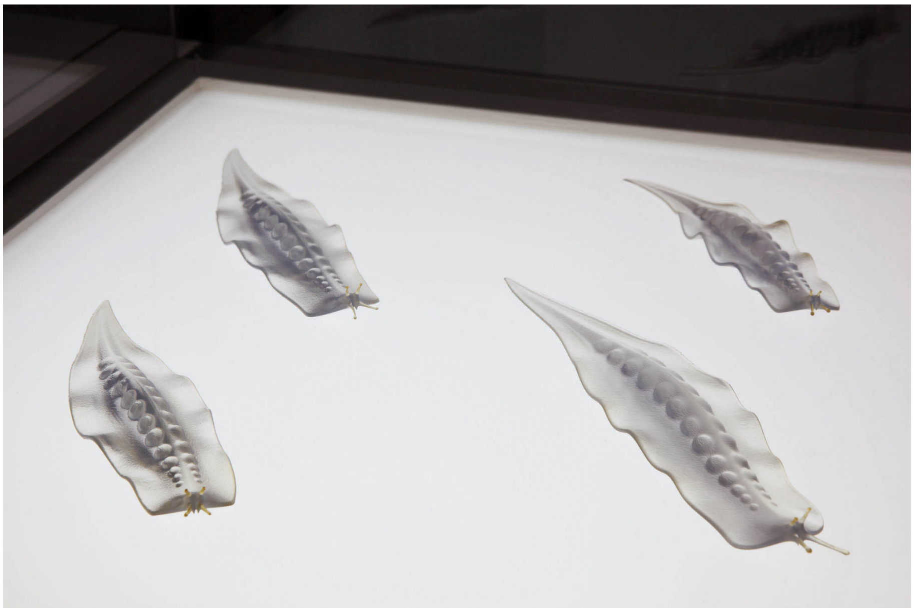

Figure 5.18
Installation view of light box and "Mobile Bioremediation Unit" models from *Designing for the Sixth Extinction* at ZKM (2015). When viewed from above they look transparent and seem to disappear.

Figure 5.19
Installation view of the light-box edition of "Rewilding with Synthetic Biology" at the "What Design Can Do" exhibition (2015), Stedelijk Museum, Amsterdam.

the impact comes not from the risk of it being mistaken for real. What is disturbing is realising that this vision is neither good nor bad, but complicated.

To test further how to manage realism and context, I experimented with designing different works for expert and non-expert audiences in my next projects, "Alternative Roads" and *Design Taxonomy* (see Chapter 3). Responding to *Dezeen* and MINI's brief for an "original vision" for synthetic biology and mobility, my imagined system critiqued both current industrial practice and synthetic biology's disruptive dreams. For SynbiCITE's synthetic biology experts, I delivered a workshop and report to challenge their assumptions around synthetic biology's imaginary of sustainable abundance.[48] By contrast, the *Design Taxonomy* installation for MNI's public exhibition more generally addressed how we might manufacture things differently. *Dezeen* published our work in progress for four months prior to the exhibition (figure 5.20), which let me iterate my communication. By the show opening, the project was being interpreted as intended: cars *themselves* would not evolve, but using biology might change how we think about design (see Appendix D).[49] My exhibited schematics included existing and engineered biomaterials to show synthetic biology as just a part of a possible future. The eccentric visual language steered viewers from taking the system literally: the cars' humorous features, including raincoats, sunshades, hairy insulation, and cooling holes, would "evolve" as owners copied each other. I matched the drawing style to the models to emphasise the project's illustrative nature (figure 3.12-13).

Synthetic biologists worry about speculative designs, critical or not, triggering negative press, fuelling hype, or serving the designer's interests over theirs. But this binary approach to reality and the imaginary is artificial. Synthetic biologists themselves speculate on the global potential of their work, yet accusations of hype can spark defensive reactions. The workshop for "Alternative Roads" revealed this tension. After I asked participants to reverse engineer a fictional biological car, SynbiCITE co-director Paul Freemont, who has helped devise official visions like the UK *Roadmap*, queried, "How can we speculate?" and, "What's the point of speculating?" He argued that a technology must evolve; it can't be shaped. He repeated this comment to a design panel I was chairing at the field's industry conference, SynBioBeta London 2015, ruing that only designers have the luxury of speculating while scientists chip away at foundational science. I commented that the entire conference was a financial speculation.[50] I also know Freemont enjoys speculative critical design.[51] At the workshop, he asked how past

48 The workshop was useful, but I suspect the report wasn't read. SynbiCITE wanted to publish it for their commercial and academic partners. Since we originally agreed that the report would be an internal working document, I requested support to secure image permissions for the heavily illustrated document; despite mutual willingness, this stalled. A second workshop, or video, may have been a better output.

49 In June, website *PSFK* covered the project, quoting me saying: "Synthetic biological cars could evolve and mutate as they are used and repaired so they become better adapted to their environments, just like living organisms", citing *Dezeen* (Piras 2014). But I hadn't said this to *Dezeen*; I had questioned how new materials might change our interactions with them (Hobson 2014b). In July, I postponed an interview request from *Fast Company* until the design work was resolved (see Peters 2014c). A *MailOnline* report and interview with me in September kept the flow of my responses (Griffiths 2014).

50 Freemont meant that scientists have to work out the details to realise the science, but speculation is intrinsic to scientific practice, from sociotechnical or technoscientific imaginaries to the formulation of hypotheses (see Latour & Woolgar 1979).

51 Our co-curation of "Grow Your Own..." at Science Gallery Dublin included speculative works (see figure

Figure 5.20
The "*Dezeen* and MINI Frontiers" (2014) microsite published work in progress prior to the exhibition.

Figure 5.21
"Rewilding with Synthetic Biology" print, bought in 2016 by Ginkgo Bioworks, and visible from inside their new organism foundry in Boston, MA.

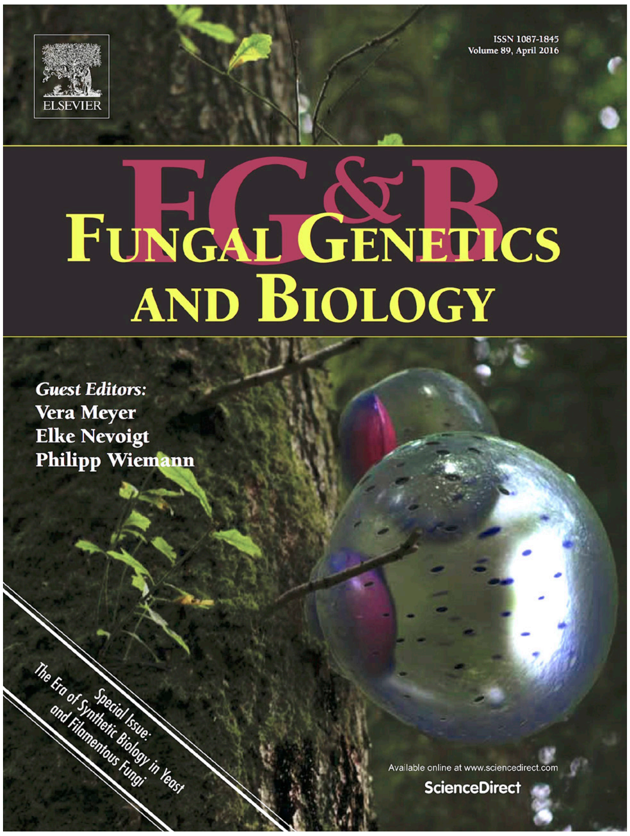

Figure 5.22
The "Self-Inflating Antipathogenic Membrane Pump" on the cover of *Fungal Genetics and Biology*'s special issue on synthetic biology. The work was discussed in the editorial (see Meyer et al. 2016).

technologies have deployed speculation to drive visions. This reluctance to detail the imaginary may be an effort to control it, in case it fails to deliver. But acknowledging the imaginary as a designed space could enable future collaboration on alternative visions.

Nevertheless, some synthetic biologists are enjoying using my critical fictions for internal debate. In a neat narrative circle, in 2016 Ginkgo Bioworks bought an edition of *Sixth Extinction* for its new "organism foundry", a facility for designing and building synthetic organisms (figure 5.21). The "Membrane Pump" appeared on the cover of a special synthetic biology issue of the mycology journal *Fungal Genetics and Biology* (figure 5.22). The editorial, "The Art of Design", used the work to question what scientists should make: "With this fictitious patent, Daisy hits the nail on the Janus-faced head: Fungi can be friends or foes; how we decode and reprogram them to suit global needs, is limited simply by our intelligence, ingenuity, and imagination. What seems like today's science fiction, could become tomorrow's reality" (Meyer et al. 2016). Synthetic biologists Victor de Lorenzo et al. (2016) were inspired by the project for their provocative paper on global bioremediation, published to spark discussion. To my knowledge, neither *Design Taxonomy* nor *Sixth Extinction* have been appropriated (yet). Certainly, the latter has been more successful; its careful, unsettling perpetuation of the imaginary has encouraged synthetic biologists to debate choices they make now.

Positioning Critical Design

My critical design work in synthetic biology is sometimes misunderstood: some think I'm promoting it, some that I'm a technological pessimist.[52] This in/out interpretation oversimplifies synthetic biology and the need to scrutinise its dreams of better. Seeking to balance collaboration, critical independence, and impact for expert and non-expert audiences, I extended Jasanoff and Kim's sociotechnical imaginary concept in practice, through experimenting with my position relative to the technoscience, its stakeholders, and imaginaries. I worked within the field (iGEM, WISB), outside it (GYO, "V&A Friday Late: *Synthetic Aesthetics*"), and on "Alternative Roads" and *Design Taxonomy* and *Sixth Extinction*, I began inside, moved outside, then took the work back in. Location affected my projects and their impact.

Situating myself inside society, outside of the technoscience and its imaginaries, gave me critical independence to challenge those imaginaries. For *Sixth Extinction*, a self-initiated commission for "Grow Your Own..." (GYO), I worked with scientific advisors, not collaborators (see Dunne & Raby 2014a, p.54). It was my strongest project aesthetically, and the most troubling conceptually. This could be described as "adjacent" collaboration, the mode that ultimately failed for Synberc's anthropologists (Rabinow & G. Bennett 2012, p.91). It also resonates with "agonism-antagonism"

5.2). From 2010, Freemont helped formalise the relationship between his CSynBi synthetic biology centre at Imperial College London (the precursor to SynbiCITE) and the RCA's Design Interactions department, including annual projects and workshops.

52 Two authors assuming that I am promoting synthetic biology appear to be triggered by my choice of language in the text for my early project *The Synthetic Kingdom* (2009), the caption for which mixes fiction and description. Both authors use the project to raise questions I intended to provoke. Yet both appear to think that I agree with the synthetic biologists' better, rather than my work revealing my troubles with those views. See Heavey (2012, p.11, p.196), and Roosth (2017, p.55, p.199).

(Barry et al. 2008), since I reinserted the work into the technoscience for debate. "Outside" projects GYO and the Friday Late (see Chapter 6) also let me pursue my interests, whilst being collaborative. I had to accommodate synthetic biologists' imaginaries and needs, but the cultural institutions were stabilising, allowing me control.

By contrast, working inside the technoscience and its imaginaries triggered competing agendas, removed my agency, and raised issues around normativity. iGEM 2014's Art and Design initiative offered insights into the imaginary's workings, and proximity provided opportunity for experimentation and to bring others in. But, as Chapter 2 explained, I was compromised. After iGEM informed me in 2015 that they were taking art and design "in a different direction", they replaced me with journalist Dan Grushkin, a synthetic biology enthusiast and co-founder of the NYC community laboratory Genspace. Grushkin co-chaired with Agapakis, keeping much of our original rubric and wiki material, but he renamed the cross-track prize the "Applied Design Prize", focused on products and applications. Three teams entered the track in 2015, and none in 2016 and 2017.[53]

Defining independent spaces for enquiry can avoid conflict inside others' imaginaries. One reason for the decline in art and design teams at iGEM is that Grushkin started an alternative programme. Grushkin was at iGEM 2014, pitching "Synthetic Aesthetics 2.0". His resulting Biodesign Challenge (BDC) (2016a) "offers art and design students the opportunity to envision future applications of biotechnology".[54] Reviewing his proposal at iGEM and afterwards, I pressed him to make it more critical. The BDC (2016b) embodies Grushkin's idea of design as mediator between a technology and its products, a way to "anticipate and inspire new applications", while promising to equip designers to navigate issues raised by our biotechnological future. Modelled on iGEM, with "themes" like energy and materials, the BDC is institutionally stabilised by art and design schools, culminating in a final round judging "summit" at MoMA, New York. In 2015-16 nine US schools competed; in 2017 there were 24, including the RCA.

Although the competition is situated outside of the technoscience, offering critical independence, it follows Myers' biodesign, positioning itself within synthetic biology's imaginaries of better. Students are asked to address a problem, describe how their proposal "may be adopted in the commercial world", and even build websites as "faux advertisements" to showcase ideas (BDC 2016c). Confusingly, projects should be "based in reality", yet students must "consider technology that will likely become available five to ten years from now". Some work with biological matter, others speculate. Teams have scientific advisors, although many projects depart from scientific reality. While some speculative projects openly used fiction to question sociotechnical issues, the more "realistic" solutionist approach encourages students to present speculation as reality.[55] With sponsors including synthetic biology companies Intrexon

53 The track's winning team from the School of Visual Arts, New York (SVA NYC iGEM 2015), successfully produced BioBricks. At SynBioBeta in March 2017, iGEM's Kim de Mora told me that integrating art and design was, after all, better.

54 The BDC's 2017 team registration fee of $1000 is significantly lower than iGEM's.

55 *The Quantworm Mine* by Liv Bargman and Nina Cutler from Central St Martins won the BDC 2017 (T. L. Jones 2017). Their fiction about earthworms bioremediating disused mines in South Wales offered a humorous and sophisticated exploration of sociotechnical issues, challenging the BDC brief from within. *POM*, the RCA's

and Ginkgo, alongside Kickstarter and the FBI, the BDC risks serving others' dreams of better, while artificially polarising speculation and reality.

Participation in iGEM was tricky as a track chair, but for art and design students, exposure to the field trains them to distinguish between imaginaries and realities and choose their position. Even without engineering biology, the ArtCenter iGEM 2014 students incisively probed promises of sustainable abundance. Embedded in the lab, the Paris Bettencourt 2014 team's designers contributed to imagining real and speculative products; to research, opening new ground for the science, and to aesthetic and critical exploration (see Appendix B). The BDC's independence offers participants greater freedom, but it lacks the agonistic reference point. Proximity to synthetic biology's imaginaries at iGEM exposes trouble in a way that the BDC's rubric obscures.

Figure 5.23
Design Taxonomy (far right) in a 3D scan of the "*Dezeen* and MINI Frontiers" exhibition (2014). This promotional show was located inside a ticketed design fair.

Unlike iGEM, my "Alternative Roads" and *Design Taxonomy* projects weren't embedded in the technoscience. But their context still constrained critique (figures 5.20, 5.23). *Dezeen's* curatorial role insulated me somewhat from MINI's marketing demands. And I had introduced the brief to SynbiCITE to circumvent their marketing needs: discussions with SynbiCITE 2013 about funding a novel PhD design fellowship stalled when it became clear that I would have to manage their visual identity and public engagement (see Appendix D), which I worried could compromise critique. Having two "clients" let me layer my interactions between synthetic biology and design. I saw the WISB residency as a second chance to develop an experimental design role funded by science (see Appendix C). Again, conflicting expectations proved irresolvable when WISB's director expected me to use my work to promote, not critically explore, their imaginary.

Another way to create new critical spaces is to infiltrate the technoscience and its imaginaries. My talks to synthetic biology audiences are sometimes performed "interventions". When

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entry (each school sends one team to MoMA) proposed assisting flies to be pollinators in a bee-free future, but it is less clear whether their speculation is scientifically possible (Alderson-Bythell et al. 2017).

SynBioBeta London 2016's organisers invited me to do a staged "fireside chat" with Ena Cratsenburg, Senior Vice President for Consumer Products at Intrexon, I saw an opportunity to mark new space for critical design in industry.[56] Our odd, pre-scripted conversation publicly normalised interaction between our promotional and critical agendas. Cratsenburg suggested that "everything the consumer touches can be made better", pushing Intrexon's consumer-centric approach to selling synthetic biology; I asked: "What is better?"

The imaginary's mechanics can be revealed from the inside. In 2015, I was invited to the UK Synthetic Biology Leadership Council's (SBLC) "*Roadmap* Refresh" workshop. Shell's Lionel Clarke, the SBLC co-chair, had also chaired the original *Roadmap's* "independent panel" of authors who supposedly "set out to reflect a representative view drawn from across the UK community" (UK SBRCG 2012, p.3).[57] By contrast, the update was just engaging "stakeholders" who, judging by the ballroom of scientists, funders, industry and defence employees, plus a few social scientists and myself, did not include "society". Responsible Research and Innovation (RRI) was constantly referenced at the workshop.[58] Social scientists are being tasked with RRI in UK synthetic biology, replacing "downstream" ethical, legal, and social implications (ELSI) work, as pioneered in the 1990s by The Human Genome Project's ELSI programme. Supposedly, RRI considers and responds to ELSI issues *throughout* the research, development and commercialisation process. But the *Roadmap* workshop discussions made RRI sound more like a reactive checklist to encourage public confidence than anticipatory thinking. Responsibility was equated to biosafety; innovation was unquestionably good. The social scientists agreed when I suggested we discuss what "responsibility" and "innovation" mean, or could mean; but synthetic biologists did not engage.

The ensuing update, *Biodesign for the Bioeconomy*, lacked a vision or discussion of values beyond the UK and its commercial interests. It also radically misrepresented Synthetic Aesthetics as a case study, saying that it "brought together artists and designers with scientists, to beautify or better communicate the science of synthetic biology" (SBLC, p.24). Our book explained that "some people have assumed that our aim is outreach: a public relations activity on behalf of synthetic biology to beautify, package, sanitize, and better communicate the science", clarifying that "We reject and actively resist such a framing. Our project has been an explanatory investigation of the intersection between art, design and synthetic biology, encouraging dialogue and dissent" (Ginsberg et al. 2014 p.xviii). The error was telling: despite our efforts at using critical practice to encourage internal critique, insiders still assumed our work celebrated their

56 Intrexon owns Oxitec and its engineered mosquitoes (see Chapter 4), and Okanogen Specialty Fruits' engineered non-browning apple. It has a majority stake in AquaBounty, whose AquAdvantage Salmon, promoted as "The World's Most Sustainable Salmon" is engineered to grow twice as fast as regular salmon; the FDA took two decades to approve it (Ledford 2015b). Intrexon also acquired biological toy company BioPop, which makes dinosaur-shaped vials filled with glowing dinoflagellates. As part of Intrexon's strategy to promote biotechnology to consumers, BioPop's founder, Andy Bass, was made Chief Executive Officer of Biological and Popular Culture. In 2017, he took Cratsenburg's role; she has moved to Ginkgo Bioworks.

57 At Shell Global Solutions (UK), Clarke's job title was Team Leader, Biodomain and Open Innovation. The UK Synthetic Biology Roadmap Coordination Group (2012, p.34) and the SBLC (2016, p.33) had similar membership: representatives of government agencies and funding councils, scientists in academia and industry. The *Roadmap* had two social scientists, Nikolas Rose and Jane Calvert, while the SBLC had only the synthetic biology industry-supporting Joyce Tait.

58 RRI's four phases are anticipation, reflexivity, inclusion, and responsiveness to technologies and their potential implications (Stilgoe & Macnaghten 2013).

imaginary, revealing conflicting views on design's role here. We decided to take advantage of this mistake to access the core of the political visioning process.

As we discussed how to address the SBLC's error, Drew Endy asked my co-authors and me if we would rather be activists fighting from outside, or "entryists" infiltrating a group to subvert it from within. We toyed with establishing a "Shadow" SBLC that would incorporate missing societal voices to cultivate alternative visions. Entryism resonated with my work in the field and its imaginaries. The vision-makers would be our audience, but we would use their strategies instead of overtly antagonising them. We highlighted the mistake in a letter to the SBLC, which we also published on the Synthetic Aesthetics website. We challenged the SBLC's adoption of (bio)design, explaining that "Design does not only serve industry and economic growth; good design enables citizens and society and should serve the common good." We argued for society to be seen as a stakeholder and suggested that the SBLC broaden its membership from a "select group of experts with a controlling stake in the technology" (Ginsberg et al. 2016a). The SBLC corrected the report.[59] Then they asked us to take down the letter, concerned that the perception of dissent could affect political support, jeopardising the field.[60]

I was struck by the perceived influence of art and design on synthetic biology's imaginaries, and the potential for careful troublemaking as a critical design tool. We kept the letter in the public realm, noting the correction in a second blog post, while reiterating that what good design meant still needed discussion, as did the SBLC's belief in art and design just as tools for public engagement.[61] Arguing as insiders for "open, inclusive and interdisciplinary discussions about synthetic biology and all its future directions", we publicly exposed the imaginary's political issues and structures (Ginsberg et al. 2016b). Unlike my iGEM experience, here we were working inside, on our terms.

Working from outside the imaginary generally gave me more control to deliver projects to my agenda, which were more likely to have impact. Regardless of starting position, having synthetic biologists as an audience provides opportunities for troublemaking, reflection, and instigating change. All my projects created some level of trouble for me. This indicates a bigger positioning problem: that of the technoscience relative to "society" itself.

The Human Genome Project's ELSI programme placed social scientists and bioethicists downstream of the scientific work, further entrenching a view that societal issues were "consequences" of the science, rather than shaping it (see Rabinow & G. Bennett 2012, p.13). Standardised practices like ELSI and RRI still cement this one-way flow of knowledge from science to society, with social science as buffer. Dunne and Raby (2005) innovatively positioned critical design upstream of society, alongside ELSI. But speculating on the "social, cultural and

59 The updated text explained that Synthetic Aesthetics led to the "consideration of futures that might transcend current industrial framings".

60 The SBLC's co-chair was George Freeman MP, then Minister for Life Sciences. Still, the report clarifies that it represents stakeholder views, not government policy.

61 The *Roadmap* recommends that "Integrating social sciences, humanities and arts researchers can help with understanding of, and engagement with, such issues and thus foster responsible innovation" (UK SBRCG 2012, p.19). But their aim is also "acceptance by public of SB as norm" (2012, p.2). Acceptance, not debate, is expected as the end result of downstream engagement.

ethical implications of emerging technologies" is still responsive, not anticipatory. Shifting the engagement further upstream (e.g. Auger 2012; Kerridge 2015) still keeps critique downstream of the imaginaries shaping what gets made. This model fails to challenge the technological determinism—even fatalism—I encounter in discussion about technologies, from lamentations that "You can't stop progress!" or "It's our moral duty to pursue all directions. Once the technology exists, then we decide."

The linear model allows synthetic biologists to decry the public's lack of knowledge, complaining that "If only they understood they would want it!"[62] Consequently (especially in the UK), increasing the public's understanding through "public engagement" is seen as the remedy to this "deficit".[63] Yet better understanding of a technology has been shown to lead to greater uncertainty, not acceptance (Durant & Legge 2005).

I began this PhD thinking about upstream and downstream positions. I occasionally provoke synthetic biologists by reversing the assumed flow of information, describing my work as "scientific engagement". I want them to reflect on their knowledge deficit about the "public" whose interests should be integral to—and should shape—the technoscience they are creating. The same publics that synthetic biologists promise to ameliorate are funding synthetic biologists' research, as they determine better's meaning for those publics.[64] But scientific engagement is an imperfect provocation. It still separates science and society, perpetuating the "two cultures" of science and humanities (Snow 1960). Instead of this linear model, we need to see society/the world as the context for technoscience, shaped by society.[65] Then we can use critical design alongside STS to break open the field's construction of imaginaries, reintegrating society's interests into those processes, keeping open the space critical design has constructed for dialogue and dissent.

62 In the UK's 2010 public engagement exercise, the *Synthetic Biology Dialogue*, the "public" asked of the scientists: "How do you know you are right?" (Bhattachary et al. 2010, p.7). Rather than answering this fundamental question about science and society, the report is generally cited by the field to show that dialogue happened.

63 Social scientists coined the "deficit model" in the 1980s. For more deconstruction of the myth of the public's attitudes to GMOs, see Marris (2001).

64 For more on imagined publics, see McNeil and Haran (2013).

65 See Stirling (2008) for challenges to the linear model and the need for "opening up".

5.3 Conclusions

My 2009 conversation with Jony Ive about growing products may have been less awkward today as synthetic biologists embrace biological design. But what they design, and who gets to decide what constitutes good design, demands critical scrutiny more than ever. Synthetic biology is limited by its engineering, scientific or industrial imagination. As my projects reveal, synthetic biologists are keen to control these imaginaries. But they alone should not decide what better means, framed by their notions of the desirable future (see Hurlbut 2015a).

The mutual colonising of design and synthetic biology to serve economic dreams of better is troubling: the emerging biodesign platform promotes imaginaries of better without challenging the economics, ethics, and politics underpinning them. It could make critical design harder to see, and to do. With growing commercial and state civil and military investment, we need work that forensically examines synthetic biologists' dreams of better. [66]

Artists and designers working with this emerging technoscience unavoidably engage and even perpetuate its imaginaries. Critical work demands understanding of the context of our interventions. That enables navigation of imaginaries, as *Sixth Extinction* did through controlling the design's consumption, the ethical design of fictions, by clarifying intentions, constituting audiences, and positioning the work. But control over work is, and should, be limited, to avoid didacticism.

Critical design can work in and on sociotechnical imaginaries, rather than their downstream implications, helping to reconfigure the linear science-to-society model to re-establish society as the context for technoscience. Informed by my troublemaking and finding, the final chapter proposes the design of "critical imaginaries" to question dreams of better, creating "other spaces" to reconnect to society.

66 Since 2012, the majority of US federal government investment in synthetic biology research has come from the US military, including DARPA (Kuiken 2017).

Figure 6.1
The Live Lab in the V&A's Grand Entrance at the "V&A Friday Late: *Synthetic Aesthetics*" (2014).

Chapter 6. The Design of Critical Imaginaries

6.1 Introduction

Nestling between the marble columns of the grand entrance to the Victoria and Albert Museum (V&A), the glowing, plastic-wrapped laboratory looked incongruous. A large circle cut into its façade invited visitors to talk to the SynbiCITE synthetic biologists inside, who were experimenting on cultures of living things (figure 6.1-2). Meanwhile, from deeper in the museum an ethereal bellowing was reverberating off the Raphael Gallery's treasures, produced by the speculatively resurrected vocal cords of the extinct hominid *Australopithecus afarensis*, part of *The Opera of Prehistoric Creatures* (2011-) by Marguerite Humeau. These interventions were just two of twenty workshops, talks, screenings, and installations that featured in the "V&A Friday Late: *Synthetic Aesthetics*", a one-night "biological takeover" of the world's leading museum of art and design (see Appendix G).

I had been invited to programme the monthly "Friday Late" in April 2014 as the launch event for the *Synthetic Aesthetics* book. Working with the V&A's Contemporary Architecture Design and Digital curators, we explored the design of biology through the work of artists, designers, scientists, and engineers, introducing an unfamiliar scientific theme into the V&A's galleries. We also introduced unfamiliar matter. In addition to our atrium laboratory, against the Tapestry Gallery's fifteenth-century Italian masterpieces—designs made by humans from biological materials—we juxtaposed designs made by biology (figure 6.3) with *Faber Futures* (2012-), a series of silk cloths printed by soil bacteria, cultivated by designer Natsai Audrey Chieza.[1]

Sheila Jasanoff (2015b, p.339) observes how the same material can be used to build different sociotechnical imaginaries: no future is inevitable, they are made. Placing designed biology against 5000 years of humanity's creativity—a legacy far longer than modern science—the Friday Late explicitly positioned synthetic biology as a product of culture. Walking the museum's galleries, I noticed that we had reframed synthetic biology against history, not futures. The identical material shown at the Science Museum would have been subsumed into a narrative of technological progress and innovation, propagating the separation of technoscience from culture, rather than seeing technoscience *shaped* by culture. The Friday Late offered a different view on biological designs and their place in the world.

1 Museum visitors are teeming with bacteria, but displaying bacteria presented novel challenges for the V&A's conservators, who had to decide whether the pigmenting species could infect our cultural heritage. To be safe, Chieza's textiles were freeze-dried. This had not been an issue at "Grow Your Own…" at Science Gallery a few months earlier.

Figure 6.2
David Willetts, Minister for Universities and Science looking into the Live Lab laboratory staffed by SynbiCITE synthetic biologists at the Friday Late (2014).

Figure 6.3
Prints made by pigment-secreting bacteria, cultured by Natsai Audrey Chieza as part of *Faber Futures: Fold* (2012-), installed in the V&A's Tapestry Gallery at the Friday Late (2014).

However, this was not an independent curatorial exercise. As the various interests involved tussled to control the narrative of synthetic biology's imaginary, it became political. The Engineering and Physical Sciences Research Council (EPSRC), a Synthetic Aesthetics co-funder, wanted to invite David Willetts, then UK Minister for Universities and Science, and synthetic biology advocate, to introduce our authors' talk.[2] I hoped to avoid politicising the event to encourage a more neutral space for contemplation; my co-authors agreed. Then, just two weeks prior to the Friday Late, synthetic biologist Drew Endy asked to cancel it, anxious about introducing the field to the UK public with such a low budget and minimal planning. I reassured him I would make it work, and pressed on. Willetts turned up on the night in a personal capacity, enjoying the lab (figure 6.2), and introducing our authors' panel, endorsing the event. Despite the encroachment of others' imaginaries, the V&A's institutional strength was stabilising. For one evening, for over 4000 people, we staged an imaginary of science and technology led by culture and society. This alternative space offered new perspectives on the imaginaries that shape our material realities.

This thesis has argued that the social imaginary should be a subject for critical design. Since the imaginary is a designable fiction, it can also be a critical design *object*. Reflecting on my projects—from repositioning biotechnology within culture at the Friday Late, trying to design a critical competition within iGEM, or imagining fictional policies shaping design objects in *Designing for the Sixth Extinction*—I realised that they partially fulfil Jasanoff and Kim's sociotechnical imaginary criteria: they constitute shared visions that are publicly performed, and stabilised by (sometimes fictional) institutions. But my projects are not sociotechnical imaginaries, alternative betters or resistant imaginaries, since they do not propose "desirable futures" enabled by science and technology. Instead, they examine this very notion as they investigate the imaginary's promised social order. They are prototypes for what I call "critical imaginaries".

In this chapter, through discussion of my projects and others', I demarcate the critical imaginary as an alternative space for enquiry. What unites these artworks, experiments, events, exhibitions, installations, and fictions is the creation of spaces that examine dreams of better as they manifest in the world, or that challenge the idea of a singular better future. Critical imaginaries address the troubles I encountered working within others' imaginaries, such as iGEM, discussed in Chapter 5. Having "triangulated" critical design's position relative to technoscience, society, and imaginaries, I begin by shifting its location to delineate more independent, heterotopian "other spaces" that are not better, but *different*.[3] Next, I show how these critical imaginaries can offer different temporal perspectives to speculative critical design (SCD), "decoupling" SCD from the linear fiction of progress to allow us to see other ways of being. Finally, I propose critical imaginaries as generative terrains that are emergent, interactive, and non-didactic.

Like sociotechnical imaginaries, critical imaginaries are world-building exercises. But these worlds are designed to investigate values. They do not determine what is better, but serve to

2 In 2013, at The Sixth International Meeting on Synthetic Biology (SB6.0), at Imperial College London, Willetts announced £24m funding for Imperial's new SynbiCITE centre (C. Smith 2013).

3 In social science, "triangulation" means using more than one method to throw light on a problem (see Mertens & Hesse-Biber 2012). I use the term cartographically, as if the imaginary has a physical presence that can be navigated. This infers we can enter inside the imaginary and design it too.

remind us that alternatives are possible. Hopeful and troublesome, they reclaim agency in the present. They could complement STS techniques, contributing to the "emergent form of critique" sought by STS scholars Jane Calvert and Pablo Schyfter (2017).

6.2 Triangulating Critical Imaginaries

Other Spaces

I began this PhD planning to elicit what better means by imagining "alternative betters". In "Alternative Roads" and *Design Taxonomy* (see Chapter 3), I experimentally designed a "critical utopia" informed by expert engagement, using optimistic language to critique the status quo.[4] However, the project's weakness owed less to didacticism or utopianism than to the fact that my critique was obscured.[5] My playful aesthetic insulated the project from being interpreted as "real", but made it look more like a naive proposal for what better could mean than an effort to foreground today's choices that make this "better future" unlikely. The vision was too low-tech to spark hype, but synthetic biologists were unlikely to appropriate it since it didn't emphasise the technoscience. However, the fixing community (see Chapter 1) did absorb it into their resistant imaginary: Fixperts' Daniel Charney included it as a "maker manifesto" in his exhibition "Brave Fixed World" (2014).[6] Still, the alternative better was not the approach I sought.

At WISB, I planned to explore the centre's "resistant imaginary". But I soon discovered that I lacked sufficient independence from that imaginary to reflect on it (see Chapter 2). By contrast, instead of negotiating others' imaginaries, my earlier work, *Sixth Extinction*, more successfully created an alternative world for testing in—a fictional "mesocosm"—to question conservationists' and synthetic biologists' dreams of better.[7] With its imaginary forest and hyperreal rendering of an ecosystem, *Sixth Extinction* manifests differently from the Friday Late. However I classify both as prototype critical imaginaries, revealing some of their essential qualities.

Sixth Extinction simulates a world where society appears to have agreed on what the "desirable future" constitutes, enacting it through its institutions and technologies. At first, it seems utopian: the lush greenery and the contrived beauty appear to show a perfect but impossible

4 "Critical utopia" was coined by literary critic Tom Moylan (1986) in *Demand the Impossible*, describing a shift in the utopian novel from the 1970s. Pertinent here is that these critical utopian societies, written to critique existing ones, are described in more detail, and are also imperfect (Levitas 2011, pp.197-200). Aware of utopia's limitations, critical utopias reject utopia "as blueprint while preserving it as dream" (Moylan 1986, p.10).

5 Dunne (1997, p.82) identified didacticism and utopianism as a risk of following Ezio Manzini's (1994) proposal that designers should use their skills to promote desirable alternatives.

6 See Appendix A for exhibition details.

7 A microcosm is a restricted system at laboratory scale, while a mesocosm is an outdoor experimental system for testing within. It is enclosed, but not necessarily isolated, and contains different organisms interacting at different trophic levels.

society that ineluctably critiques the present.[8] But deeper contemplation of its supporting systems exposes this neat technological solution as an unsettling compromise. Whose interests are served by infecting nature to save it from us? What happens to the remaining nature? *Sixth Extinction* is not utopian, since it doesn't embody an image of the good life or propose what that good life is, nor does it offer a vision to work towards (Levitas 2011, p.1).[9]

Throughout the twentieth century, critics discredited utopias for being unrealistic, indulgent, or even "highly dangerous", inciting totalitarianism (Levitas 2011, p.3).[10] Today, some scholars are rehabilitating the concept. Ruth Levitas (2011, p.9) defines utopia as "the expression of the desire for a better way of being", proposing it as a method not a goal, a "critical tool for exposing the limitations of current policy discourses about economic growth and ecological sustainability" (2013 p.xi).[11] *Sixth Extinction* is similarly motivated, prioritising process over outcome. Yet it is not predictive, desirous nor dismissive of any one future. It uses design, critically, to reveal complex social, political, and economic forces around imaginaries of better. As such, it has more in common with the heterotopia, a more disturbing "other space". Philosopher Michel Foucault (2005 p.xix) identified the concept of heterotopia in 1966 after enjoying Jorge Luis Borges' account of an apocryphal Chinese encyclopaedia and its arbitrary animal classification system.[12] Challenging how we think the world is ordered, the encyclopaedia's alternative categories shatter norms, creating new knowledge. Heterotopias are "both different and the same, both unreal and real", and neither good nor bad (Johnson 2016).[13]

The Shit Museum (or Museo Della Merda) in Castelbosco, Italy, is a heterotopia. Every day, Gianantonio Locatelli's 3,500 cows produce 50,000 litres of milk and 150,000kg of manure. Locatelli has installed biodigesters that transform the dung into electricity (figure 6.4). However, he isn't promoting a utopia of sustainable abundance, but contemplation of transformation. Locatelli mixes the bio-digested excrement with clay and straw to make terracotta that is "50% shit". He and architect Luca Cipelletti use this patented Merdacotta® to make tableware, and even toilets. Their simple vessels are no better than other designs; the provocative use of "shit"

8 More's (1516) island of Utopia was a play on the Greek *outopia*: no place, and *eutopia*, the good place. Early utopias like this were located somewhere else in the world, unreachable in space. Utopias can also be located elsewhere in time, like the future.

9 Some utopians seek to catalyse the social change they imagine (Levitas 2011, p.6). For individuals' vision to become sociotechnical imaginaries, they must be shared.

10 Utopias infer dystopia: one man's utopia is another's dystopia. "Utopias are dreams of collective deliverance that in waking life are found to be nightmares" (Gray 2007, p.17). Architectural theorist Reinhold Martin (2016) blames contemporary distaste for utopia on both the failures of modernistic urban planning (and its perceived authoritarianism) and contemporary "techno-euphoric neoliberalism".

11 For another practical rehabilitation of utopia, see Wright (2010).

12 Borges (1999, p.231) recounts the encyclopaedia's taxonomy: "On those remote pages it is written that animals are divided into: (a) those that belong to the Emperor, (b) embalmed ones, (c) those that are trained, (d) suckling pigs, (e) mermaids, (f) fabulous ones, (g) stray dogs, (h) those that are included in this classification, (i) those that tremble as if they were mad, (j) innumerable ones, (k) those drawn with a very fine camel's hair brush, (l) others, (m) those that have just broken a flower vase, (n) those that resemble flies from a distance." For more on Foucault's heterotopia, see Topinka (2010).

13 In 1967, Foucault (1984) introduced heterotopia to architects who, along with urbanists and geographers, adopted it to describe urban spaces of difference (e.g. Dehaene & De Cauter 2008). He suggested diverse spaces as heterotopias, from cemeteries to Persian carpets, brothels, Jesuit utopian colonies, ships, gardens, holiday resorts, Muslim baths, prisons, asylums, museums, and libraries.

Figure 6.4
Biodigesters painted by artist David Tremlett (2010-12) in Castelbosco, Italy, are part of the Museo della Merda heterotopia.

Figure 6.5
These simple homewares produced under the Museo della Merda brand (2016) are made from Merdacotta, a mixture of bio-digested cow dung and terracotta, questioning ideas of value.

Figure 6.6
Interior view of the Museo della Merda, opened in 2015. Rather than promoting sustainability, this heterotopian space explores transformation.

in name and matter underwrites their makers' interest beyond palatable solutions (figure 6.5). In Locatelli's castle they have created a museum that scrutinises faeces in culture, from alchemy to philosophy (figure 6.6). Their heterotopia—which broke through the politesse of Milan Design Week 2016 by winning the Milano Design Award—offers complicating perspectives on sustainability and transformation. Eating off a "shit" plate forces the user to consider when something becomes waste, and when it becomes valuable again.[14]

Similarly, creating a different space for questioning what better could mean was intrinsic to the exhibition "Grow Your Own... Life After Nature" (GYO), for which I led the curatorial team of Anthony Dunne, SynbiCITE co-director Paul Freemont, biohacker Cathal Garvey, and Science Gallery director Michael John Gorman (see Appendix G). Located at Science Gallery Dublin, which brings art and science together in a non-didactic way to encourage discussion about science, the show had over 45,000 visitors during its three-month run from October 2013. GYO asked visitors to consider some of the "potentially ground-breaking applications and uncertain implications of synthetic life" to equip them "to help shape future discussions around synthetic biology" (Ginsberg et al. 2013). Working from a cultural space allowed some independence from synthetic biology's agendas; still, the Wellcome Trust funded the show, and Freemont, willing to speculate and critique, also sought positive public engagement.[15]

The exhibition prioritised openness. The first installation visitors encountered was a glazed laboratory, also visible from the street (figure 6.7). This "Community BioLab" hosted an ambitious programme of week-long residencies for artists, designers, scientists and biohackers from around the world. Residents ran workshops, gave talks, and worked on projects in this public space.[16] The main events programme explored issues from hype, with science journalist Alok Jha, to the first event of the President of Ireland's Ethics Initiative, with Drew Endy in discussion with Hugh Whittall, Director of the Nuffield Council on Bioethics. Across the exhibition's three rooms, twenty works from biological experiments to speculative fictions (see figure 5.2) addressed synthetic biology's imaginaries. "Grow Your Own... Life" dealt with life as designable matter; "Grow Your Own... Society" considered designed biology's interaction with societal and ecological systems, and "Grow Your Own... Machines" examined synthetic biology's machine metaphor.

Echoing the sociotechnical imaginary's definition, GYO presented an imagined world of synthetic biology, which was "institutionally stabilised" and "publicly performed" within Science Gallery.[17] However, the role of the technoscience was not fixed in this future, nor was it necessarily desirable. The only desirable future presented was one where a technoscience is openly discussed and questioned within society. As a heterotopic space for informed interaction

14 Is Merdacotta®, made from processed and sterilised dung, still dung? I debated this publicly with Cipelletti at "Toilet Break" hosted by *Dirty Furniture* magazine at the London Design Festival 2016. The provocation is fascinating in the context of synthetic biology's efforts to engineer and patent the human gut microbiome.

15 The Wellcome Trust is one of the world's largest medical research charities. The show was funded by one of their Society Awards.

16 Detailed in Appendix G.

17 GYO informed my programming of the Friday Late, including the public laboratory, with some projects overlapping.

Figure 6.7
The Community BioLab in the entrance of “Grow Your Own… Life After Nature”, Science Gallery Dublin (2013-14).

with imaginaries, not the public acceptance of them, GYO was also a prototype critical imaginary.[18]

Foucault conceived of heterotopia as a literary tool, which Anthony Dunne (1997, p.42) touched on as inspiration for critical design. Critical designer Björn Franke (2010) expands this link to explain critical design fictions' odd status as simultaneously real and unreal designs. For Franke, these "heterotopian objects" are located *alongside* reality, not in the future, as often understood. In Chapter 5, I rejected the linear model that puts technoscience upstream of society, with critical design (and social science) as intermediaries, preferring to view society as the context for technoscience. Placing critical design alongside reality fits this reconfiguration. Positioned in society, critical design can reflect on society's imaginaries, not just the downstream implications of the technologies they shape. Instead of making alternative betters, or resistant imaginaries, *Sixth Extinction,* GYO and the Friday Late suggest how the critical imaginary could offer a practice-based technique to examine sociotechnical imaginaries. These more independent "other spaces" allow us to reflect on better, without prescribing its meaning. The next sections detail their qualities further, distinguishing them from SCD or STS approaches.

Temporal Perspectives

SCD is usually triangulated to time, appearing as futures, alternative presents, or counterfactual histories.[19] Echoing Franke's "heteropian objects", DiSalvo (2015, p.86) reasons that speculation is not just used as "projection", but also for reflection. Indeed, speculation has its roots in *speculum*, the Latin for mirror. Boris Groys (2015, p.33) vividly describes speculation as "reflection on the mirror, not merely the reflection in the mirror". Arjun Appadurai (2015, p.207) elaborates on this link between reality and its reflection:

> [...] speculation is always a normative project which seeks to introduce the ought to the is, without denying to each its special force. This characteristic lends to speculation a special tension for speculation does not simply pose what could be or what should be against what is. Rather it re-imagines what is in the image of what could or should be. Thus speculation is never narrowly utopian. It remains connected to the force of what is already found around is.

Speculation is not didactic; it creates a dialogue of reflections between how the world *is* and *could be*. The critical imaginary actively uses this heterotopian mirroring to reflect on the frameworks that shape our reality.[20] In this section, I consider how, like SCD, critical imaginaries can manifest as future fictions. But their focus is less on reflecting how things could or should be than on offering different perspectives on the present, and through this the potential for change.

18 Synthetic Aesthetics similarly was an effort at "opening up" science to more perspectives, which Calvert and Schyfter (2017) describe as a trait shared with STS (see Stirling 2008).

19 Describing critical work as speculation can cause confusion in other contexts, since speculation is often associated with time and/or money. In finance, speculations are economic transactions that trade on the future (see Esposito 2011). In commercial design, "spec" or "speculative" work is unpaid, in hope of a commission.

20 Foucault (1984, p.4) saw the mirror as both a utopian and a heterotopian space: "The mirror functions as a heterotopia in this respect: it makes this place that I occupy at the moment when I look at myself in the glass at once absolutely real, connected with all the space that surrounds it, and absolutely unreal, since in order to be perceived it has to pass through this virtual point which is over there."

Our orientation within temporal space is culturally constructed: the modern Western perception of time maps paths forwards.[21] This conception supported the myth that progress is working towards a future optimum.[22] Recalibrating both critical design and its speculative techniques to prioritise reflection on reality (rather than on time) "decouples" critical design from the fiction of progress. Collapsing this topology can offer different perspectives on better. For example, like all objects the plastic bottle simultaneously embodies past life, and present and future potential. The oil it is made from contains dead life; we choose to borrow that oil from future things that could have been. Contemplating the bottle away from its dominant linear production narrative reminds us that futures are designed in the present, for example through sociotechnical imaginaries, and the design of those futures influences our present. This is not to deny the existence of "the future", but rather to reclaim agency over it.

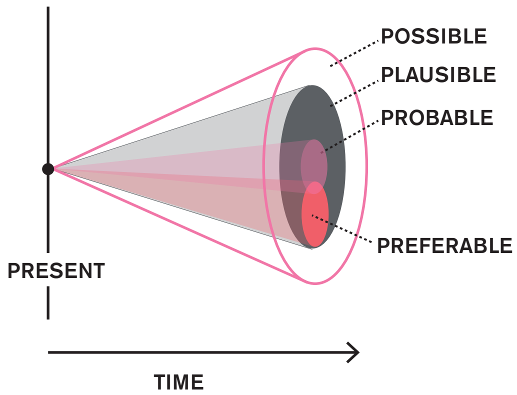


Figure 6.8
The Futures Cone offers a fixed vantage point from a singular present onto a multiplicity of futures. Adapted from Voros (2001) and Dunne and Raby (2014).

Speculative critical designs are reflective: they do not aim to "describe perfect or desirable worlds but more nuanced or neutral possibilities" (Auger 2016). Still, they slot into the linear temporal model by, as Auger (2012, pp.250-1) explains, allowing the viewer to choose between futures and decide: "Is this better?" The "futures cone", often used to explain this technique, promotes this interpretation (figure 6.8).[23] The diagram situates the viewer gazing from a single "now" towards a vista of futures. Present and future are separated, with some futures appearing objectively better than others. Like this, speculative design appears to be about helping us identify "desirable futures", rather than interrogating that very concept. Crucially, choosing between futures makes it look as if the future, not the present, is where change happens. This model also makes critical speculations such as *E. chromi* more likely to be appropriated as goals as they slot into possibility space, just as science fictions become inspiration for scientists (Bassett et al. 2013).

21 We use language to visualise time in space (Rosenberg & Grafton 2012, p.13), and language, as Armen Avanessian (2015, p.13) explains, is itself a fiction. For more on time, history, and modernity, see Koselleck (2004), and on the philosophy of time, Markosian (2014). Uchronia, or no-time, is a kind of alternative history, or fictional time period; for more on its potential as a critical design method, see Schmid (2017).

22 Rather than dismissing progress outright, some thinkers find other ways to critique it. A group of radical thinkers, under the banner of "accelerationism", advocate a speeding up of technological progress to precipitate the collapse of capitalism (Srnicek & A. Williams 2013). Journalist Thomas Friedman (2016) writes about how to succeed in an "age of acceleration".

23 For more on the futures cone in speculative design, see Candy (2010), Auger (2012), and Dunne and Raby (2014). It was adapted from Joseph Voros' (2001) interpretation of Norman Henchley's (1978) concept.

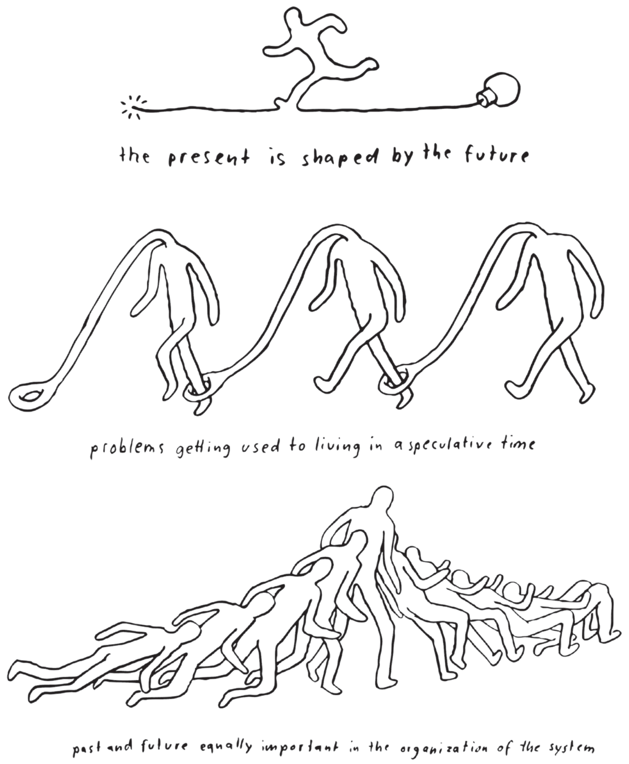


Figure 6.9
Recognising a more complex interplay between past, presents and futures than the cone, the "speculative-time complex" is playfully explored in a collaboration between philosopher Armen Avanessian and illustrator Andreas Töpfer (2014; 2016).

We need alternative perspectives on this linearity, which the critical imaginary offers. Time's direction is not fixed.[24] Indeed, philosopher Armen Avanessian and critical studies scholar Suhail Malik (2014) argue that advanced technological societies are experiencing a reversal of time's linear order. Now, "the future happens before the present, time arrives from the future" (figure 6.9).[25] Their "speculative-time complex" is evident in sociotechnical imaginaries, where desirable futures influence the present. Critical imaginaries that use future fictions make use of this reverse linearity. *Sixth Extinction*'s imagined world, articulated in its timeline diagram (figure 4.5), is located in a future. But my aim was to place agency in the present. It shares characteristics with both "exploratory" and "normative" futures models used by futurists (European Commission 2007). Exploratory futures (figure 6.10)—like future-facing SCD—stretch past or present trends forwards to generate alternative futures, which are not necessarily desirable. These "what if...?" speculations can then inform potential changes in direction towards preferred futures. By contrast, normative futures begin with an imagined, desirable future and travel backwards, tracing how that future may or may not emerge, helping users to identify actions to take or avoid now (figure 6.11).[26]

24 For research on individual time perspectives, see Zimbardo & Boyd (1999). Philosopher Slavoj Žižek (2012, p.134) notes that the French language has two words for future. He defines "futur" as what will be, i.e. the "continuation of the present," whereas "avenir" is what is to come", suggesting a "more radical break" with the present. The German language doesn't allow the individual temporal fluidity: you move along a forward axis, unlike in English, where a meeting "pushed back" can be sooner or later, depending on our perception of ourselves in time. Some see themselves moving forward in time, for others, time moves towards them (C. Hammond 2012 p.133).

25 Avanessian and Malik (2016) see evidence for this in use of terms like "pre-emptive strike", "post-modern", or "post-internet".

26 In the 1950s and 1960s, the burgeoning field of corporate futurology recognised this. R. John Williams (2016, pp.473-4) argues that the scenario planners' pursuit of the future was less about prediction than seeking

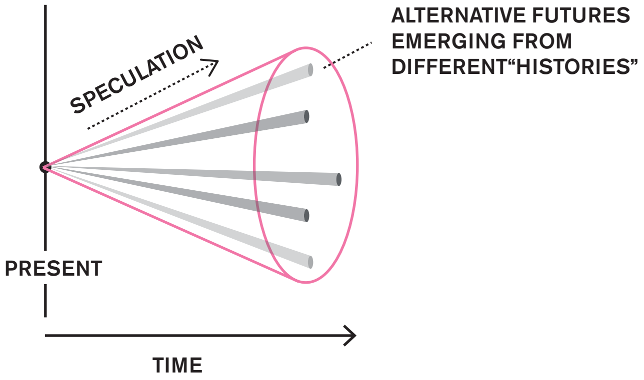


Figure 6.10
"Exploratory futures" extrapolate forwards from a current (or past) event to see what futures may be possible, regardless of their desirability.

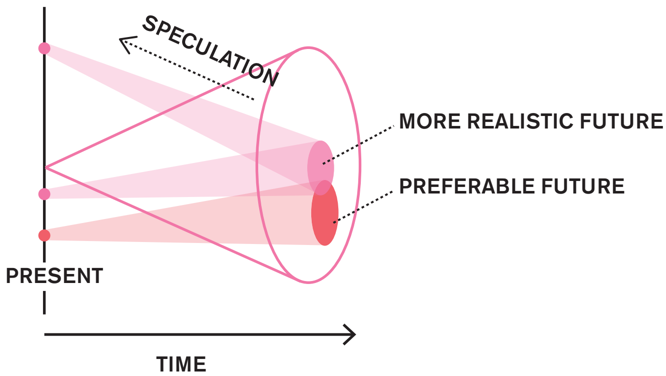


Figure 6.11
"Normative futures" ask what future we desire, then work inwards to speculate on present choices, with the ambition of activating the desired future.

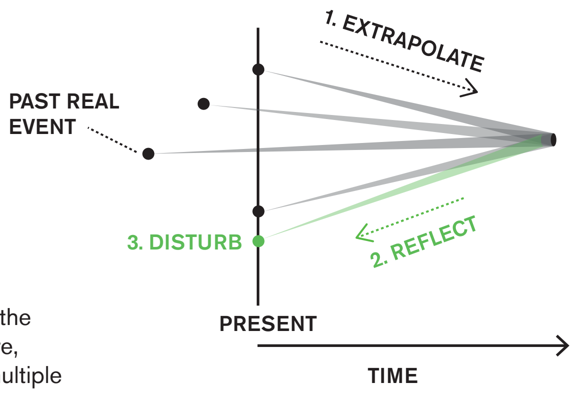


Figure 6.12
Extrapolating from the present into a future, then returning to multiple presents, *Designing for the Sixth Extinction* uses speculation to create an alternative space to reflect on, and even disturb, the present.

Like exploratory futures, speculative designs, critical or not, are inevitably informed by others' imaginaries as they extrapolate them. Similarly, *Sixth Extinction* uses the future as a vantage point to consider how research and policy choices in the past and present could transport us to a future. However, it travels in two directions (figure 6.12). Unlike Auger's SCD, the intention is less to enable debate about which future is better, but, like exploratory futures, to foreground the human choices determining technologies' trajectories now. However, unlike normative or exploratory models, *Sixth Extinction* does not define what is better. It highlights the existence of simultaneous, conflicting betters. Just as Dunne and Raby (2014a, p.2) describe using speculation to imagine possible futures to better understand the present, *Sixth Extinction* wrenches us back into the present, demanding that we address the constitution of better. As a critical imaginary, it extends Franke's or Dunne and Raby's reflective critical design: it not only offers perspectives on presents, it seeks change too. Its insertion into the spaces where synthetic biology's imaginaries are being constructed now, through presentations and publications, could potentially disturb the form of those imaginaries it is reflecting on. Dislodging SCD's forward-looking perspective, *Sixth Extinction* operates from the future to challenge better now.

Critical imaginaries, even rendered as future fictions, weave into our present with the potential to modify it.[27] These fictions are not just for consumption, they offer interactive, exploratory worlds for testing within, creating new ways of seeing the present, and changing it. In the final section, I explore this capacity to create new possibilities.

Generative Terrains

Simultaneous worlds are fundamental to utopian thought; Brazilian educator Paulo Freire identified this "dialectic of denouncing one reality while announcing a new reality [...]. This is to be in two realities simultaneously, to live to dream and to dream in order to produce the emancipated conditions for a future living" (see Sember 2015, p.152). As a heterotopian space that offers alternative perspectives on the present, the critical imaginary does not prioritise a particular reality: it reflects the multiple betters that co-exist through our individual experiences. This can create possibility and agency by reminding us that things can be different. The critical imaginary can use temporal devices other than the future perspective to create generative, co-existing realities, further differentiating it from SCD and STS techniques.

In James Joyce's (2000, p.30) *Ulysses*, history's arbitrary linearity is questioned by the character Stephen:

> Had Pyrrhus not fallen by a beldam's hand in Argos or Julius Caesar not been knifed to death? They are not to be thought away. Time has branded them and fettered they are lodged in the room of the infinite possibilities they have ousted. But can those have been possible seeing that they never were? Or was that only possible which came to pass?

"a plurality of possible futures" that they saw as equally likely, inspired by a countercultural enthusiasm for the "presumed nonlinearity of 'Eastern' temporalities".

27 Science fiction can serve this purpose, to some extent. This function has recently gained more prominence with current political change, via dystopian social science fictions or "speculative fictions" like Margaret Atwood's (1986) *The Handmaid's Tale*.

Those events that "came to pass" may, like the plastic bottle, be marked from all the things that could have been, but Stephen's imagined room imbues them all with latent possibility. Some scientists believe that our universe exists alongside a collection of parallel universes: a multiverse where many possible worlds could co-exist.[28] Multiverse or not, fiction can help us simulate other worlds within our own. For example, counterfactual histories disrupt the course of history to allow the imagination of a different present.[29] We can design worlds with different rules to reflect on the function of our own world, like the novel *Roadside Picnic* (B. Strugatsky & A. Strugatsky 1977), where landscape zones operate under alternative laws of physics.[30] Or, we can design "alternative nows", as Dunne and Raby have, to "explore how things could be right now if we had different values" (Moggridge 2007, p.589).

Critical imaginaries can also create alternative presents, but they allow these parallel worlds to coexist with our own, reflecting reality's complex multiplicity. "I leave to several futures (not to all) my garden of forking paths", the Argentinean novelist Jorge Luis Borges (1998, p.125) wrote in his tale of multiple unfolding futures. Rejecting the linear future, *The Garden of Forking Paths* suggested a metaphysical garden, located in time, not space. From it grew proliferating possibilities. Its diverging paths could also converge: the same event might be reached through alternative routes. Borges was drawing on the problem of "future contingents", statements about future events, actions or states that are neither true nor false. Aristotle explained this problem using the story of a sea battle planned to take place tomorrow (see Øhrstrøm & Hasle 2011). If the battle is cancelled the day before, while it was once true, it is now also false. Borges' garden reminds us of the impossibility of promising a single better future. While we have some agency over the paths we choose, the future is unstable. This makes change possible.

My prototype critical imaginaries begin to embody this quality. Like other SCD projects, *Sixth Extinction* fleshes out a world through its imagery, models, and fictional patents. But my later timeline diagram (figure 4.5) foregrounds that world's contingency: pivoting on current discussions between conservationists and synthetic biologists, it reminds us that social and sociotechnical imaginaries are emergent (Miller 2015, p.281). The diagram insinuates that other worlds could come to pass, destabilising any projected certainty. The Friday Late also hinted at the possibility of other worlds existing, as it fleetingly manifested a culture-led science paradigm alongside the dominant one. Such co-existence is explicit in Agnes Denes' iconic *Wheatfield - A Confrontation: Battery Park Landfill* (1982) (figure 6.13). Juxtaposed with Manhattan's skyline, *Wheatfield* starkly showed another way of being, contingent on somebody's choices. These projects show that different worlds—whether imaginary and real, or conflicting ideas of better—can co-exist.

A critical imaginary could, like Borges' garden, offer multiple perspectives on simultaneous events, negating a single "reality". This idea becomes more clear through the artistic trio Troika's heterotopian installation *Dark Matter* (2014). The suspended black object (figure 6.14-15) is coated in light-absorbing black flock; as the viewer walks around it, its form shifts from square

28 For more on multiverses, see Carr (2007).

29 For more on counterfactual histories and their implications, see Evans (2014). For a speculative critical design example, see Sascha Pohflepp's *The Golden Institute* (2009).

30 The novel was the basis for the screenplay of director Andrei Tarkovsky's film *Stalker* (1979).

Figures 6.13
Agnes Denes' *Wheatfield - A Confrontation: Battery Park Landfill, Downtown Manhattan - With New York Financial Center* (1982) brought attention to the contigency of the dominant imaginary of better. Denes harvested over 1000 pounds of wheat from two acres of land worth $4.5bn.

to circle to hexagon. Unifying such logically antithetical profiles forces us to question ingrained beliefs about how we interpret the world. [31]

While *Dark Matter* offers norm-shattering perspectives on a single event, a critical imaginary could manifest Borges' multiplicity and contingency. Evolutionary biologist Richard Lenski's (2016) simultaneous evolution experiment suggests how. In February 1988, Lenski distributed genetically identical cultures of *E. coli* into twelve flasks. 60,000 generations later, each population has its own parallel history, contingent on mutations and battles between sub-populations (figure 6.16). Twelve individual worlds co-exist in time and space. Although a scientific experiment, it could be interpreted as a critical imaginary that invites reflection on evolution. The experiment's "liveness" separates this approach from the multiple scenarios of conventional futures planning, which project out to imagined "end states" (Fahey & Randall 1998, p.10). Rather than reflecting from a future to see other ways of being, as *Sixth Extinction* does, this kind of critical imaginary could have unpredictable, concurrent strands generating new perspectives and possibility.

The potential created from tangible immersion in other possible worlds further differentiates critical imaginaries from text-based approaches like STS (Calvert & Schyfter 2017, p.15). For example, artist David OReilly's computer game *Everything* (2017) is a "philosophical terrarium" (Partin 2017). Travelling through the game's universe, the player can embody (almost) anything, from atom to moose to oilrig to planet (figure 6.17). This anthropomorphisation offers us a fictional, but useful, perspective on human ideas of better. However, since the experience operates within the game's defined philosophical narrative (Bogost 2017), based in object-oriented ontology, the game is not entirely emergent, so is not fully a critical imaginary.[32]

Interactivity and immersion, combined with emergence, distinguish the critical imaginary from world-building exercises, like intentional communities, world fairs or military training games, that have fixed value systems.[33] Dunne and Raby's *The School of Constructed Realities* (2015) explicates this difference (figure 6.18). Dunne and Raby transformed a satellite building of Vienna's MAK museum into a fictitious design school dedicated to "generating multiple versions of reality", exhibiting their projects as case studies in its "classrooms".[34] Physically placing the viewer into the fiction, reconfiguring their position to reality, the gallery becomes a space for imagining, creating emergent potential.

31 Troika often "collaborate" with forces like electricity or erosion, embracing emergence to challenge Enlightenment values of human primacy.

32 Speculative realism, and within it object-oriented ontology (see Harman 2010; Bogost 2012), are contemporary philosophical approaches that reject correlationism (see Meillassoux 2010): humans are no longer the linchpin to verify something's existence, and those things have equal status, whether living, non-living, or conceptual, that cannot be reduced down. This post-human ecological approach has been critiqued for reducing human agency to make change (e.g. Charlesworth 2015).

33 Intentional communities are also live, but dictate a single ideology and can collapse if they depart from it. At world fairs, countries present different, but static, worldviews within an immersive, designed experience, for propaganda (Barbrook 2007). International art or design biennales are similar, but have greater potential for experimentation and so could offer opportunity for testing critical imaginaries.

34 Dunne & Raby's (2014b) short story, *The School of Constructed* Realities, is the project's basis. The show included their short film *Meinong's Jungle* (2015). Rendering philosopher Alexius Meinong's 1904 proposed taxonomy that includes non-existent and even impossible objects, their aesthetic language provides possibility for design exploration. A critical imaginary could be a non-existent philosophical world that reflects our own.

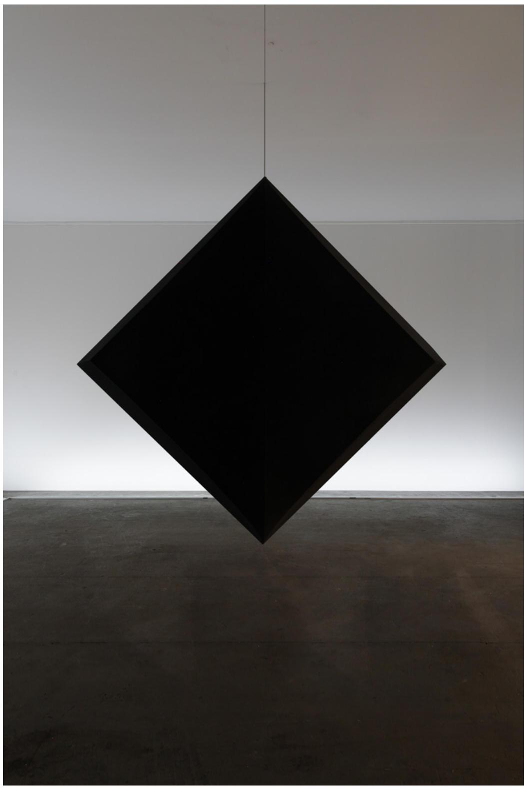
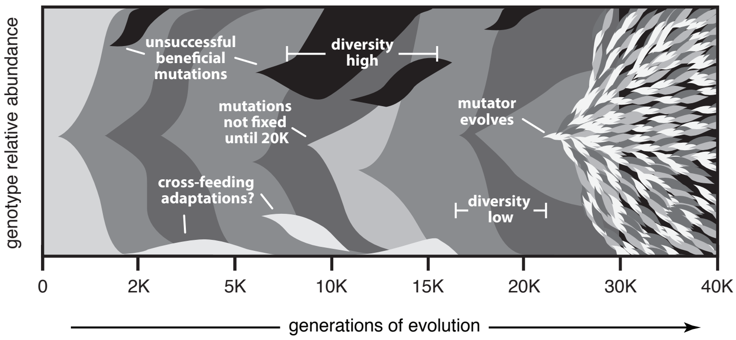


Figure 6.14-15
Dark Matter (2014) by Troika (Eva Rucki, Conner Freyer, Sebastien Noel) challenges the viewer's assumptions as it unites a series of seemingly antithetical profiles in a single form.



Figures 6.16
Mutational diversity within one of twelve once-identical populations of *E. coli* in Richard Lenski's project *Long-term Experimental Evolution* (Barrick & Lenski 2009). Since 1988, Lenski has tracked the populations' parallel development, making contingency (and hence possibility) tangible.

Figure 6.17
Still from the video game *Everything* (2017), by David OReilly. Navigating through *Everything*'s world, the user can embody (almost) any animal or object, shifting between things and scales.

Figure 6.18
One “classroom” in Dunne amd Raby’s installation *School of Constructed Realities* (2015) for MAK, Vienna. In this room, their work from *United Micro Kingdoms* is juxtaposed with a decorated salon in a fictional seminar set-up.

The critical imaginary can use rules to generate possibilities, as artist Philippe Parreno experimented with at London’s Tate Modern. The choreography of *Anywhen*’s (2016) massive panels and lights and film was determined by data harvested from a small, hidden yeast culture (figure 6.19-20). The yeast-as-algorithm provided innumerable configurations for the work; meanwhile, the viewer searched for meaning within the world’s construction.[35] By contrast, photographer Joan Fontcuberta (2005) creates new worlds from rules already determined by others. For *Orogenesis* (2002-6), he fed images of canonical artistic representations of landscapes into software that renders topography from cartographic data for scientific and military purposes (figure 6.21-22). The resulting fictional terrains make visible rules that structure our world. In a third variant, designer Bastiaan de Nennie disregards convention, devising his own rules to create new worlds from existing matter. For *The Digital Virtuosity* (2015) he 3D-scanned objects, then deconstructed them in digital space before playfully recombining them into new objects (figure 6.23). Creating possible worlds from existing matter, these projects all show characteristics of the critical imaginary.

Mixing interactivity and contingency encourages democratic possibility, exemplified in architect Lina Bo Bardi’s 1968 display system for the São Paulo Museum of Art (MASP), which she also designed. Bo Bardi hung the museum’s collection on “crystal plinths”—glass sheets inserted into concrete bases—so that the artworks appear to float (Pedrosa & Proença 2015).[36] The gallery has no dividing walls, allowing each visitor to navigate their own route through the collection, generating vistas and connections (figure 6.24). As a critical imaginary, this political architecture creates a non-didactic space, reminding us that alternatives are possible. It allows for simultaneous worlds that reflect our diverse experiences of reality.

Manifesting as artworks, architecture, events, or computer games, critical imaginaries create emergent, interactive, and democratic spaces, whether rendered within fictional landscapes or

35 Similarly, Pierre Huyghe’s fantastical biotope in a disused ice rink, *After ALife Ahead* (2017) at the Skulptur Projekte Münster, contains multiple interconnected emergent elements, which permanently affect the installation. The shell of a cone snail living in the installation has been scanned; this pattern provides a score that triggers interventions in the space, including the opening of ceiling structures to allow the weather in, which changes the conditions of the living landscape inside (Luke 2017).

36 Removed in 1996, Bo Bardi’s scheme was reinstated in 2015.

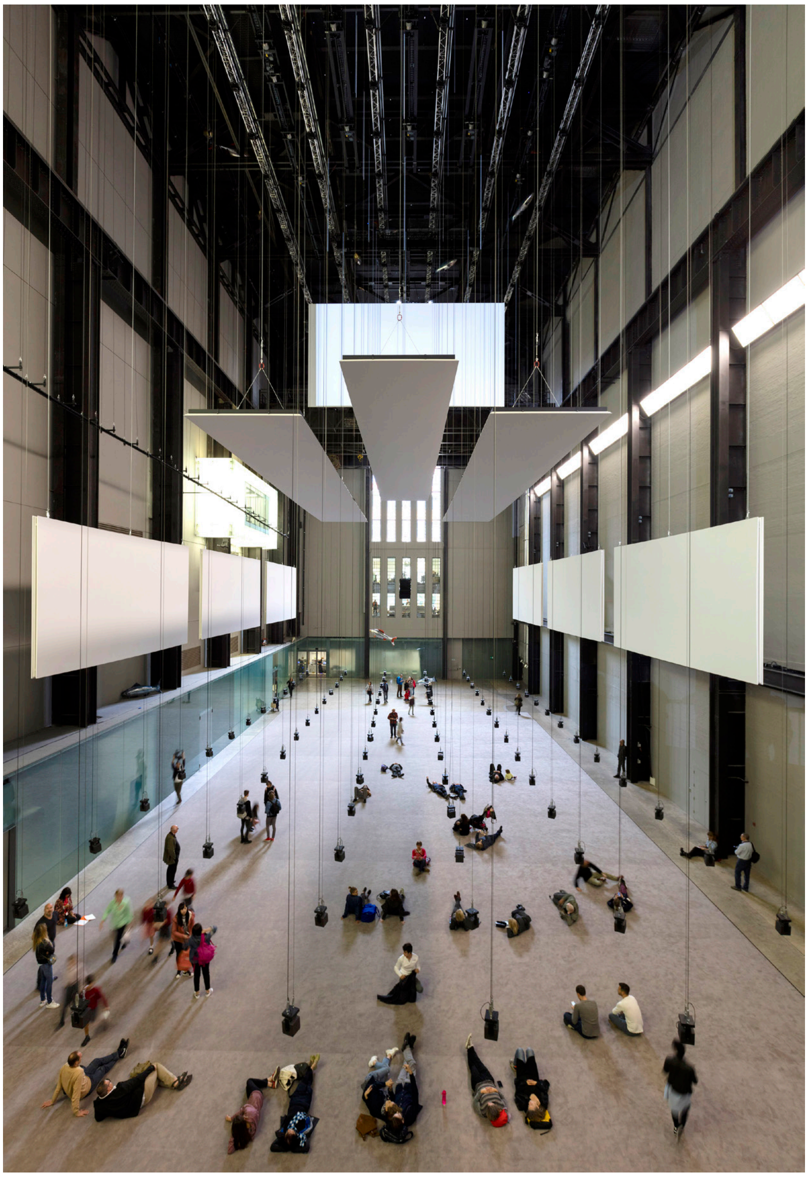


Figure 6.19
Anywhen (2016), by Philippe Parreno, generates its choreography based on the data produced by a yeast culture. The culture was located in the small room (just visible) at the far left end of the Turbine Hall at Tate Modern, London.

Figure 6.20
Yeast cultures and apparatus measuring data from Philippe Parreno's *Anywhen* (2016).

Figure 6.21
Joan Fontcuberta's *Orogenesis: Fenton (after Roger Fenton's The Valley of the Shadow of Death, 1855)* (2004). A fictional landscape rendered from a representation of a real landscape, using free mapping software.

Figure 6.22
Roger Fenton's *Valley of the Shadow of Death* (1855), the dataset for Fontcuberta's landscape.

Figure 6.23
Bastiaan de Nennie 3D-scans common objects and, disregarding scale, impossibly recombines them in digital space according to his own, undisclosed rules in *The Digital Virtuosity* (2015). This motorbike includes spray bottle and meat grinder components.

Figure 6.24
Architect Lina Bo Bardi's 1968 exhibition display system for the Museum of Art São Paulo generates a democratic experience of the museum's collection.

real ones. These “generative terrains”, separated from the fiction of the optimum and its single better future, offer other perspectives. Reminding us that new imaginaries can be made from existing material, they begin to help us imagine what those other worlds could be.

6.3 Conclusions

Reviewing the photographs of the Friday Late, the image of David Willetts peering into the lab stood out: a politician contemplating scientists’ experiments in a cultural institution. By reconfiguring contexts and values, for one evening we created a novel view on the same material. This observation led me to define the critical imaginary’s qualities through my and others’ projects.

The critical imaginary, like STS, encourages reflection on sociotechnical imaginaries, not just their material implications. By playing with critical design’s position in relation to society and time, the critical imaginary provides alternative perspectives onto our present. Experimenting with contexts and rules to create other worlds, these heterotopian spaces also reflect the multiplicity of betters within our simultaneous experiences of reality. Critical imaginaries are not alternative betters, like *Design Taxonomy*, or resistant imaginaries, as I tried exploring at WISB; instead, they remind us of the possibility of alternatives, giving us agency in the present. They are disturbing, and hopefully troublesome. Their generative nature differentiates them from SCD’s preferable futures, or STS’s analytic methods: they not only reflect on values, but help us to imagine what else could be. My projects *Sixth Extinction*, the Friday Late, and GYO show some of these qualities. In the conclusion, “Better Dreams”, I suggest my next steps developing the critical imaginary.

Conclusion: Better Dreams

I began this thesis with my TED Global 2011 experience, where I asked: "How can we design 'better' when we don't know what the technology might look like, feel like, or how it could affect our everyday lives in unexpected ways?". I was trying to question synthetic biology's dreams of designing biology. But I couldn't yet communicate why this mattered, and why, as a critical designer, I was using design to ask questions, not solve problems. What I needed to ask was: "What is better?", "Whose better?", and "Who decides?".

Through this PhD, I learnt that "better" was the critical design tool I sought. This deceptively simple word has enabled me to navigate complex sociotechnical issues in my projects, in reflections on them, and to ask more effective questions about who determines our sociotechnical futures, and how. "Better" itself became a critical design to communicate why design should question problems, not just try to solve them.

Values shape the things we choose to make, and thus our lives. The "better" plastic water bottle, described in the introduction, embodies this matter. Design is an optimistic activity. But because it is subject to our desires, it has no absolute good. The engineer may argue that the single-use plastic bottle isn't the issue, but the problem it solves wasn't well articulated: it is a failure of optimisation. But however well-defined the brief, solving one problem with a technology reveals others. There is no universal better: the optimal design is a fiction. Progress promises to uplift all humanity, but better for some will be worse for others.

Nevertheless, I regularly encounter designers and synthetic biologists (and others) offering solutions to make the world better, but leaving better undefined. I wanted to understand why these promises were so powerful in the advanced technological societies of the UK and US, and use critical design to find new ways to ask better questions of those dreams. Classifying better as a sociotechnical imaginary, I used its framework in this thesis to address these questions, and analyse my projects. This helped me find commonalities in design and synthetic biology's promises of better, and unravel my troubles with them. I also identified ideas of better from other spaces, such as Silicon Valley, that influence synthetic biology's visions. This process let me argue that the imaginary, and not just the implications of the technologies it shapes, should be a subject for critical design.

Analysing better's meanings deepened my understanding of critical design. I defined it as an optimistic practice that challenges optimisation and the fictional optimum, concepts that fuel, and are fuelled by, capitalist betters that dominate many sociotechnical imaginaries in the developed world. Critical design tries to make other possible worlds available, without prescribing what is better. This clarified my experimental work in synthetic biology as critical, yet optimistic: I cannot escape the designer's ameliorative impulse. This insight is useful for future practice.

The plastic bottle's failure of optimisation is a useful reminder as synthetic biologists optimistically embark on the design of biology, dreaming of bettering biology, the world, and even nature. Both practice and theory helped me to distinguish these three diverging betters within synthetic biology, and elicit conflicting values underpinning each. Borrowing the sociotechnical imaginary to examine "better" offered a useful new critical design technique to spot opportunities for intervention, which could be applied to other subjects. It also elucidated the mutual colonisation of synthetic biology and design practices emerging in the new biodesign platform, explaining why critical design must navigate carefully to trouble these imaginaries successfully.

In my critical design practice, designing fictions, curating, or "intervening", I found trouble to be a useful tool, whether I was identifying, making or experiencing it. Interacting with synthetic biologists, I often encountered unequal financial and political relationships, and diverging expectations over my role. Although some projects did not go to plan, trouble still generated insight into values. But my assumptions about the position of technoscience—and critical design—relative to society shifted. The upstream/downstream model allows synthetic biologists to shape the technoscience and policy according to their conception of better. Instead, reimagining society as the context for technoscience, as the STS scholars informing this thesis do, shifts power from the technoscience's visionaries back to society.

Consequently, I suggested relocating critical design from downstream of technoscience to its societal context. This informs my proposed "critical imaginary": a more independent, heterotopian space to explore and generate simultaneous worlds to reflect on our own. Unlike my starting idea to design "alternative betters", critical imaginaries do not prescribe what is better, rather, they encourage the possibility of alternatives. This technique could complement STS analysis of sociotechnical imaginaries, and in contrast to SCD, potentially intervene in their construction.

Next Steps

I plan to develop the critical imaginary through practice, perhaps as a research laboratory outside of technoscience, with outputs from publishing platforms to installations. A first collaboration with social scientist Jane Calvert is underway. Under the working title "Another Synthetic Biology is Possible", we will create a heterotopian space to generate alternative values.[1] I encourage others to test the concept too.

I also want to create an installation containing live, parallel worlds. I am intrigued by Colorifix, a start-up engineering bacteria that dye and fix textiles. Colorifix hopes this will be measurably better for the environment than current chemical methods.[2] Suggesting a distributed manufacturing model rather than perpetuating existing industrial models, Colorifix imagines textile plants licensing their bacteria, fed on locally-available materials and feedstocks. Terroir

1 Borrowing from Isabelle Stenger's (2011) "Another Science is Possible".

2 Colorifix (2017) is a spin-off company from the University of Cambridge by synthetic biologist Jim Ajioka, based on work begun while mentoring the Cambridge iGEM 2009 team project, *E. chromi*.

could challenge colour standards. But is this *better*? Colorifix has partnered with Cambridge's Centre for Global Equality to explore the significant regulatory and educational issues raised by implementing a living dye in various developing nations.[3] Could a critical imaginary explore this complexity? Shipping dyed textiles to one venue could reveal colour variations produced by cultures grown in parallel around the world. The location of that venue could usefully complicate matters: at a design fair, the installation could open up discussion about what better means for standards, consumers, ecosystems, and labour practices.

What is Better? Whose Better? Who Decides?

This has been a strange time to write about better. An unprecedented struggle for its meaning suddenly dominated politics in the UK and the US, the sites of this thesis. Yet the few continue to define what is better for humanity and the planet. Between December 2015 and February 2017, the US National Academies shifted to allow human genome editing, with little societal debate.[4] Meanwhile, Silicon Valley's "disruptive" digital technologies continue to concentrate huge wealth and power; its leaders are now funding technosciences like life extension that may "better" the few, heightening global inequality.[5]

This thesis advocates for societal deliberation about the world we want, and for design as a technique for provoking it. It only begins to touch on better. While there is no single better, trouble doesn't mean giving up hope: we must challenge what better means. My PhD work has offered design tools for this kind of critical, optimistic practice. We should all be asking: "What is better? Whose better? Who decides?" Better matters.

3 I took part in some of these conversations in May 2017.

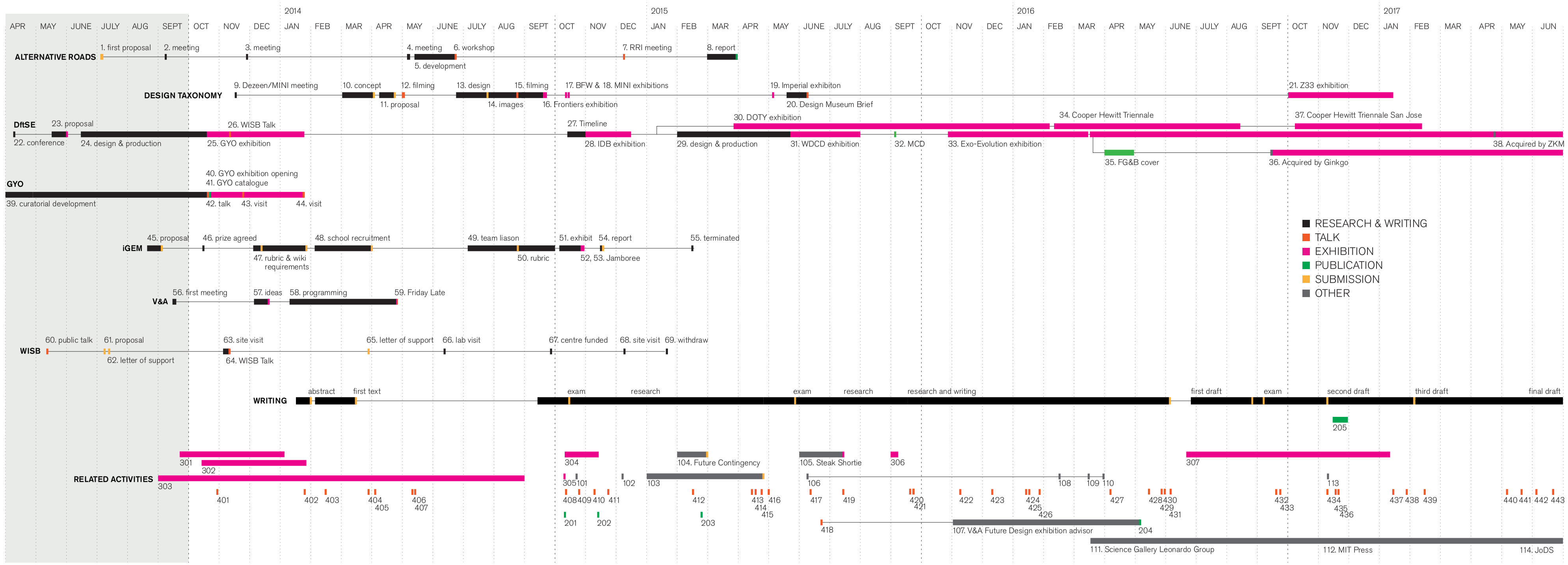
4 In February 2017 the US National Academies' Committee on Human Gene Editing: Scientific, Medical, and Ethical Considerations agreed that clinical trials for non-heritable trials were now permissible (see Chapter 4).

5 For example, as noted in Chapter 4, J. Craig Venter and Peter Diamandis are co-founders of Human Longevity, Inc.; however, Venter claims its primary objective is to live better, not necessarily longer, lives (Highfield 2016). See also Zimmer (2015). Other companies in pursuit of anti-ageing technologies include Google's spin-off company, Calico Labs (Regalado 2016b).

Appendices

Appendices B-G supplement project coverage in the chapters. Each appendix includes a project description, background, aims, credits, and processes. Projects analysed in more depth in the chapters are described in less detail here.

Appendix A: PhD Timeline



"ALTERNATIVE ROADS"

1,2,3. Discussions about fellowship or collaboration with SynbiCITE, Imperial College London.

4,5. Meet with Freemont & Kitney to inform workshop development.

6. "Repair Ecologies" workshop at SynbiCITE, 23 June 2014.

7. Attend SynbiCITE's Responsible Research and Innovation Code of Practice meeting, 10 Dec 2014.

8. Production and submission of project report for SynbiCITE.

DESIGN TAXONOMY

9. First meetings with *Dezeen*/ MINI about potential commission; attend marketing launch of new MINI.

10. Research; submission of initial concept to MINI.

11. Further development after MINI's feedback; submission of project proposal.

12. Film interview with *Dezeen*; published 23 June 2014.

13. Installation design and production building on workshop findings.

14. Production and submission of images of prototypes for MINI's press release.

15. Interview and filming with *Dezeen* of production process; published 14 Sept 2014.

16. Project exhibited at "*Dezeen* and MINI Frontiers", Design Junction, London Design Festival,17–21 Sept 2014.

17. Project graphics shown as manifesto at "Brave Fixed World", Lódz Design Festival, 9–19 Oct 2014.

18. Project exhibited at "MINI Space Festival", BMW World, Munich, 25 Oct–5 Nov 2014.

19. Project exhibited at Imperial Festival 2015, Imperial College London, 7–9 May 2015.

20. Set annual brief for the "Design Factory Higher Education" initiative, based on *Design Taxonomy*. Present and launch, Design Museum, London, 15 June 2015.

21. *Dezeen* project video shown at "Manufactuur 3.0", Z33, Hasselt, 30 Sept 2016–8 Jan 2017.

DESIGNING FOR THE SIXTH EXTINCTION

22. Attend "How will Synthetic Biology and Conservation Shape the Future of Nature?" conference, Cambridge, 8–11 Apr 2013.

23. Develop proposal for invited call for "Grow Your Own…". Commissioned by curatorial committee (excluding me).

24. Research, design, and production.

25. First exhibition at "Grow Your Own…".

26. Present project at WISB to scientific audience, some raise concerns, 21 Nov 2013.

27, 28. Redesign and frame patent images; new model and timeline commissioned for "The Future Is Not What It Used To Be", Istanbul Design Biennial, Galata Greek Primary School, Istanbul, 1 Nov–14 Dec 2014.

29, 31, 33. Negotiation and commission of light-box edition with models, supported by exhibitions: "What Design Can Do", Stedelijk Museum, Amsterdam, 21 May–1 Aug 2015 and "Exo-Evolution", ZKM | Center for Art and Media Karlsruhe, 30 Oct 2015–6 Mar 2016.

30. Nomination by Frith Kerr for Graphics category, and exhibited at "Designs of the Year 2015", Design Museum, London, 5 Mar–3 Apr 2015.

32. Ginsberg, A.D., 2015. Designing for the Sixth Extinction. In: *MCD Magazine* (79).

34, 37. Exhibited at "Beauty– Cooper Hewitt Design Triennial", Cooper Hewitt Museum, NYC, 12 Feb 2016–21 Aug 2016; touring to San Jose Museum of Art, 8 Oct 2016–19 Feb 2017.

35. Project on cover of *Fungal Genetics & Biology* (89), April 2016.

36. Print edition of "Rewilding with Synthetic Biology" acquired by Ginkgo Bioworks for new Boston organism foundry.

38. Light-box edition and accompanying works acquired by ZKM.

"GROW YOUR OWN… LIFE AFTER NATURE"

39. Lead curatorial process for exhibition at Science Gallery Dublin with co-curators Anthony Dunne, Paul Freemont, Cathal Garvey, and Michael John Gorman. Work with Science Gallery team on open/invited calls, curation, marketing, catalogue, exhibition design, events etc.

40. Exhibition launch. Runs from 24 Oct 2013–19 Jan 2014.

41. Catalogue published.

42. "Curators Talk", 25 Oct 2013.

43. Visit Community BioLab residents; attend programmed events; observe exhibition.

44. Visit for Endy and Whitall's bioethics talk; observe exhibition.

IGEM 2014 ART AND DESIGN TRACK AND PRIZE

45. Invited by International Genetically Engineered Machine (iGEM) competition to chair track; ask Christina Agapakis to collaborate (July). Research and submit report, with proposal for prize (not track), participation parameters, rules and requirements, and committee. Research assistance from Gemma Lord.

46. iGEM concedes cross-track prize plus track.

47. Write requirements, publish Track and Prize wiki pages.

48. Solicit team entries from art and design schools, 6 teams enter (drops to 5).

49. Agapakis runs team liaison.

50. Finalise judging rubric.

51. Organise jamboree exhibition.

52, 53. Judging at jamboree, 30 Oct–3 Nov 2014. Feedback session for participants: "Art & Design at iGEM" workshop, 2 Nov 2014.

54. Submit feedback report.

55. iGEM emails to explain taking track and committee in "a different direction".

"V&A FRIDAY LATE: *SYNTHETIC AESTHETICS*"

56. Approach Victoria and Albert (V&A) Museum director, Martin Roth, about a launch talk for *Synthetic Aesthetics*. Roth suggests a "Friday Late".

57. Submit programme ideas to V&A's Ruth Lie, who will curate and produce event.

58. Start leading on programming and seeking additional funding, setting up collaboration with SynbiCITE to provide laboratory, and liaising with participants, assisted by CADD curators.

59. Friday Late, 25 Apr 2014. Participate in Author's Talk and Panel, chaired by Oliver Morton, introduced by Minister David Willetts.

WARWICK CENTRE FOR INTEGRATIVE SYNTHETIC BIOLOGY (WISB) RESIDENCY

60. Introductory public talk, 23 May 2013.

61. Submit proposal for public engagement commercial job or academic research position; agree the latter.

62. Formal letter of support for the WISB centre and artist-in-residence role.

63, 64. 5-day site visit: meet scientists individually and attend lab meetings, 18–22 Nov 2013. Talk at Towards Next Generation Synthetic Biology, WISB international meeting, 22 Nov 2013.

65. Letter of support for second research centre funding bid.

66. Day of lab visits.

67. Centre funding awarded.

68. Site visit.

69. Withdraw from project.

RELATED ACTIVITIES

101. International Jury Member, Dutch Design Awards, 2014.

102. Write briefing note for Forum for the Future research on sustainability in synthetic biology, Dec 2014.

103. Jury Chair, "Speculative Concepts", *Core77* Design Awards, 2015.

104. *STATES OF FUTURE CONTINGENCY*
Project proposal submitted for *WIRED*/The Space, Feb 2015 (unsuccessful).

105. *STEAK SHORTIE*
Scriptwriting, production consulting (with Koert van Mensvoort), voiceover and intrroduction of short film for Knotty Objects conference commissioned by Paola Antonelli, Neri Oxman, and Kevin Slavin, MIT Media Lab, Cambridge, MA.

106. Attend Synthetic Biology "*Roadmap* Refresh" Workshop, Birmingham, 16 June 16 2015.

107. Curatorial advisor on biotechnology and ecology sections, V&A "Design Futures" exhibition (2018).

108. Publication of *Biodesign for the Bioeconomy* by SBLC.

109. Write Synthetic Aesthetics open letter to SBLC, 16 Mar 2016.

110. Synthetic Aesthetics blog post in response to SBLC reprinting report, 30 Mar 2016.

111. Member, Leonardo advisory group, Science Gallery London.

112. Member, MIT Press European Academic Advisory Council.

113. Round table participant, President of the Royal Society's Cultural Implications of Genetic Technologies event.

114. Editorial Board Member, *Journal of Design & Science*, MIT Media Lab, MIT Press.

PUBLICATIONS

201. Ginsberg, A.D., 2014. Robocrop. *Icon Magazine* (October).

202. Ginsberg, A.D., 2014. Synthetic biology could use some questions from humans, *WIRED* UK (November). (Opinion piece on Ecover and synthetic biology).

203. Ginsberg, A.D., 2015. Microorganism Networks. In: *Atlas of Contemporary Networks*. M. Ferrari et al., eds., 2015. Venice: Universita Iuav di Venezia.

204. Ginsberg, A.D., 2018. Reading the Small Print. In: *Future Design*. K. Long et al., eds. London: Victoria and Albert Museum. (Catalogue essay on Oxford Nanopore MinION DNA sequencer).

205. Ginsberg, A.D., 2018. Critical Imaginaries. In: *Studio Future – Future Fictions in Art and Design*, J. Boelen et al., eds. Haselt: Z33.

ADDITIONAL EXHIBITIONS

301. "Biodesign", Netherlands Architecture Institute, Rotterdam, 27 Sept 2013–5 Jan 2014.

302. "Bunny Smash: Design to Touch the World", Museum of Contemporary Art, Tokyo, 3 Oct 3 2013–19 Jan 2014.

303. "Project Genesis", Ars Electronica, Linz, 1 Aug 2013–1 Aug 2014.

304. "Sense Nonsense", Design Academy Eindhoven, Van Abbemuseum, Eindhoven, Netherlands, 18 Oct–11 Nov 2014.

305. "360˚ IV International Festival of Contemporary Scientific Cinema", Polytechnic Museum, Moscow, Russia, 10 Oct 2014.

306. "Przemiany Festiwal", Copernicus Science Centre, Warsaw, 3–6 Sept 2015.

307. "The Life Fair", Het Nieuwe Instituut, Rotterdam, 12 June 2016–8 Jan 2017.

TALKS

401. Invited participant, "Science Meets Design", Technology Strategy Board, Design Museum/ Science Museum, London, 28 Oct 2013. Discussion on design and science collaborations with Minister David Willetts.

402. Talk and panel, "How Do You Do Biodesign?", Het Nieuwe Instituut, Rotterdam, 23 Jan 2014.

403. Talk, Information Experience Design, Royal College of Art, London, 13 Feb 2014.

404. Speaker, Future Everything, Manchester Town Hall Manchester, 31 Mar 2014.

405. Keynote, National Affairs Series, Iowa State University, Ames, IA, 2 Apr 2014.

406. Speaker, What Design Can Do!, Stadsschouwburg Stadium, Amsterdam, 8 May 2014.

407. Stage conversation with Rachel Armstrong, WDCD Academy Series, What Design Can Do!, Stadsschouwburg Stadium, Amsterdam, 9 May 2014.

408. Keynote, Dutch Design Awards, Het Klokgebouw, Eindhoven, 18 Oct 2014.

409. Panellist, "Synthetic Aesthetics: New Frontiers in Contemporary Design", MoMA, NYC, 28 Oct 2014.

410. Discussion Participant, "Mutations in Nature", The Forum, BBC World Service, Nov 2014.

411. Speaker, "What About the Future?", Arkimeet, Istanbul, Turkey, 19 Nov 2014.

412. Speaker and Panellist, Grand Opening: Challenge the Challenges, Open Lab Stockholm, 12 Feb 2015.

413. Panellist, Design Academy Eindhoven "Eat Shit" exhibition, Salone Del Mobile, Milan, 17 Apr 2015.

414. Speaker, SEE #10, Schlachthof Cultural Centre, Wiesbaden, 18 Apr 2015.

415. Panel chair, "Design & Synthetic Biology, SynBioBeta, Imperial College London, 23 Apr 2015.

416. Speaker, Strelka: Future Settlements, Strelka Institute (via Skype), Moscow, 1 Apr 2015.

417. Speaker, Tomorrow Today: Design, Fiction and Social Responsibility, ICA, London, 11 June 2015.

418. Speaker, "Design Futures" exhibition development seminar, Victoria and Albert Museum, London, UK, 23 June 2015.

419. Speaker, Knotty Objects, MIT Media Lab, Cambridge, MA, 15 July 2015.

420. Speaker, Future Luxury Symposium: Future Materials, Victoria and Albert Museum, London, 21 Sept 2015.

421. Speaker, British Council Design Connections 10 x 10, Somerset House, London, 25 Sept 2015.

422. Speaker, *Synthetic Aesthetics* panel with Jane Calvert & Alistair Elfick, Border Sessions Crossing: Border Festival, The Hague, 11 Nov 2015.

423. Speaker, What Design Can Do! São Paulo, FAA, São Paulo, 8 Dec 2015.

424. Speaker, UK Responsible Research and Innovation & Synthetic Biology Platform, King's College London, 15 Jan 2016.

425. Speaker, Design and the Life Sciences with Paola Antonelli, Michael John Gorman & Alexandra Daisy Ginsberg, DLD '16, Munich, 18 Jan 2016.

426. Speaker, Living Technology, MA Fashion seminar, Royal College of Art, London, 25 Jan 2016.

427. Fireside Chat with Ena Cratsenburg, SynBioBeta London 2016, Imperial College London, 6 Apr 2016.

428. Speaker, Workshop BioDesign, Escuela de Arquitectura, Pontificia Universidad Catolica de Chile (via Skype), Santiago, 12 May 2016.

429. Panel chair, Oxford Nanopore: London Calling 2016. Altitude, London, 26 May 2016.

430. Lecture, Elucidatory Mind: Changing Stories series, Visual Communications Department, Royal College of Art, London, 27 May 2016.

431. Speaker, Supernature Symposium: Oron Catts, Alexandra Daisy Ginsberg & Natalie Jeremijenko, Information Experience Design, Royal College of Art, London, 2 June 2016.

432. Speaker, Toilet Break: Shit into Gold, Kensington, London Design Festival, 17 Sept 2016.

433. Speaker, Global Design Forum: Imagining the Future, V&A, London, 23 September 2016.

434. Lecture, Material Futures Department, Central St Martins, London, 9 Nov 2016.

435. Speaker, Biofabricate, Parsons School of Design, New York, NY, 17 Nov 2016.

436. Speaker, adidas Creative Farm, New York, NY, 18 Nov 2016.

437. Speaker, "Material as Stories" symposium, Fashion MA, Royal College of Art, London, 17 Jan 2017.

438. Speaker, "Biodesign Challenge Introduction", Royal College of Art, London, 26 Jan 2017.

439. Lecture, "The Design of Life", School of Design, Royal College of Art, London, 13 Feb 2017.

440. Lecture, Design & Politics Seminar Series: "The Dream of Better", Department of Design History and Theory, University of Applied Arts Vienna, 26 April 2017.

441. Lecture, "Patrons' Talk: The Science of Design in Biology and Robotics", Royal Institution, London, 10 May 2017.

442. Speaker, Criteria: Critical Design Conference, Sursock Museum, Beirut, 20 May 2017.

443. Speaker, SB7.0, The Seventh International Meeting on Synthetic Biology, National University of Singapore, 13 June 2017.

Appendix B: iGEM Art and Design

This appendix provides more detailed documentation of the iGEM Art and Design Track and Prize to support their evaluation in Chapters 2 and 5.

Description

The International Genetically Engineered Machine competition (iGEM) began as an undergraduate competition at MIT. Teams spend their summer using parts-based synthetic biology to "solve real-world problems" (see Chapter 2), presenting their projects for judging at the annual "jamboree" in Boston, MA (see iGEM 2017). At iGEM's invitation, synthetic biologist Christina Agapakis and I developed and implemented a new Art and Design Track at the 2014 iGEM Jamboree. We insisted iGEM offer a cross-track Art and Design Prize as well, which we also devised. This project involved working within iGEM's sociotechnical imaginary; our intervention in that imaginary involved designing rules that would shape others' work, to seed new projects and collate art and design collaborations across iGEM into a unified body of work. Working within iGEM revealed more about the mechanics of the imaginary itself. Differences in the understanding of art and design's role in synthetic biology, and what collaboration meant to synthetic biologists, complicated the process. It led me to question whether, as a critical designer, it is possible to work in, and for, synthetic biology. This project helped me to recognise the usefulness of trouble for gaining insight into the sociotechnical imaginary's machinations.

Background

Trawling through past iGEM teams' wikis and social media posts is the only way to piece together the breadth of iGEM's unofficial art and design culture. Engineering teams have sought out artists and designers as advisors (e.g. Suzanne Lee (Imperial College London iGEM 2008)); embraced them as collaborators (e.g. Howard Boland (University College London iGEM 2012)), or even included them as team members (e.g. Melanie Dutton (University of Edinburgh iGEM 2012)). Often tasked with communication design, artists and designers can, however, exert a more conceptual influence (e.g. University College London iGEM 2012). Engineering teams have themselves engaged in industrial design, integrating wetware and hardware in prototypes (e.g. Harvard University iGEM 2010), or made art for the "Human Practices" component (e.g. Hokkaido University iGEM 2011). There have been a few dedicated art/design teams, either working with scientific advisors in the lab (ArtScienceBangalore iGEM 2009; 2010; 2011), or doing speculative design work (Weimar Heidelberg Arts iGEM 2010). Collaboration generally yields the most interesting work.

Conscious of this growth, in July 2013, during the Sixth International Meeting on Synthetic Biology (SB6.0), iGEM director Randy Rettberg invited me to set up an Art and Design Track for iGEM 2014. I asked synthetic biologist Christina Agapakis to collaborate. But we soon realised that what art and design meant to iGEM—and why they wanted to formalise its inclusion—was not clear. In September 2013, iGEM HQ gave the example of the Queen's Canada iGEM 2012 team (2012). They worked with a dance troupe that "performed" the project throughout their scientific presentation. iGEM wanted the dancers themselves to be able to enter iGEM if they so wished. iGEM's motivation was "inclusivity" and "celebration", which to them meant offering a separate track for those uninterested in or unable to do wet lab work (Lizarazo 2013).

When James King and I experimentally mentored the University of Cambridge iGEM 2009 team, we did so without funding. Jim Haseloff, their iGEM advisor, later suggested we join the team at the 2009 jamboree at our own cost. King and I asked iGEM about a non-team presentation slot to show our design interventions, but this proved too expensive. So we made a portable exhibit to initiate conversation: the *Scatalog*. I offered to write a report for *WIRED* (UK) to secure a press pass and thus avoid iGEM's entrance fee. Now, for 2014, iGEM was formalising my involvement, and asking me to work for them for free. Their expectation complicated the project, as most other track chairs and judges were institutional scientists or social scientists, not independent practitioners. Creativity was once again required: I attended the 2014 jamboree thanks to Autodesk's Bio/Nano/Programmable Matter group, who sponsored my travel to the US for the MoMA "Synthetic Aesthetics" salon I helped to organise, which we scheduled to coincide with iGEM. iGEM's lack of available funding meant that this global project was conducted via email and conference call, perhaps exacerbating misunderstandings between disciplines and cultures.

Aims

Agapakis and I wanted to design a cross-competition prize that would encourage critically engaged collaborations between artists and designers and synthetic biology teams. Doing so would highlight the value of this work, formalise an emerging practice into an identifiable body of work, and provide a framework for future good practice. It would inform my understanding of iGEM's imaginary of better, how it is constructed and implemented, and whether it can be adjusted from within.

Credits and Acknowledgements

- Meagan Lizarazo, Kim de Mora, and Randy Rettberg at iGEM HQ;
- Art and Design co-chair Christina Agapakis;
- Art and Design committee, specialist judges Sara Hendren and Peter Yeadon, and iGEM judges;
- Track and Prize participating students and advisors;
- Carlos Olguin and Autodesk's Bio/Nano/Programmable Matter Group, travel support.

Process

August - October 2013: Negotiation

iGEM awards track prizes as well as special cross-track prizes, such as "Best Human Practices Advance". When Rettberg invited me to set up the track, I countered that an Art and Design special prize would be preferable (see Chapter 2), but Rettberg refused. In August 2013, iGEM requested details from Agapakis and me about our track committee (a group of expert advisors), parameters for participation, and rules and requirements. With research assistance from my studio intern, Gemma Lord, we issued a 50-page report in early September, still arguing for the cross-track "iGEM Art and Design Award". We documented past art and design engagement with iGEM to back up our assertion that interdisciplinary teams yielded the strongest work, arguing against a track that segregated art and design. The report included draft rules and requirements, a proposed advisory committee, suggestions of art and design schools to partner with, and a list of references and examples of art/design work with synthetic biology beyond iGEM, all to support our case. We explained that:

> We are excited that iGEM HQ believes that iGEM teams working hard to imagine and innovate technologies at the intersection of art, design, science, technology and society deserve special recognition for this work. We propose that in 2014 there should be a seventh Special Prize: the "iGEM Art and Design Award" (alternatively, the "Synthetic Aesthetics Award") given to the team or teams that best incorporate collaboration between artists and/or designers and scientists to use synthetic biology to challenge our expectations, or to open up new ways to think about synthetic biology as a material for design, its future, or ourselves in the context of synthetic biology.
>
> …
>
> A cross-track "Special Award" would encourage students of architecture, landscape architecture, industrial and service design, material design, communication design, arts, and many other design and fine art disciplines to contribute their expertise to the teams of engineering and science students. From this, we may see advances both in art practice, design projects that consider applications and future implications together, as well as tangible developments in areas such as material science, architecture, landscape, textiles, software and interaction design. Isolating such efforts into a separate track would limit such innovation and not reward the science and engineering teams who are continuing the existing, highly productive trend of collaborating with artists and designers.
>
> What we have learnt from our research this summer into past iGEM teams is that those that have produced the most interesting, innovative, successful and strongest art/design work have included scientists and engineers working in collaboration with designers and artists, or designers and artists with scientific advisors or members, not the teams of artists and designers alone (of which there is only one that we are aware of).
>
> There are no singular definitions for art and design, disciplines that cover a broad spectrum of practice and training and philosophies. However, what is clear is that designers and artists working in iGEM are innovating their own practice, and shaping new ways of working for the future, which should be commended. We believe the practitioners who are excited to participate in iGEM, both newcomers and existing members of the community, should be encouraged towards interdisciplinary working. Recognising the value of shared interdisciplinary expertise is a value that synthetic biology, iGEM and the Registry are founded on. The basic requirement of producing a BioBrick should apply to all teams seeking an award; encouraging innovation and advances across all tracks can only be beneficial to iGEM!

Excerpt from iGEM 2014 Art and Design Proposal, September 2013.

Our proposed requirements demanded interdisciplinary teams with "at least one scientist or engineer on the team, at least one artist or designer". Teams would work within the framework of iGEM, which meant designing and producing a BioBrick as ArtScienceBangalore iGEM 2009 had, rather than only making speculative work like Weimar/Heidelberg Arts iGEM 2010.

But iGEM insisted on the track. In September, iGEM's Meagan Lizarazo (2013) suggested by email a cross-competition "Design Prize", which I would chair, with Agapakis heading an "Art Track" for teams "who do not want to or cannot join a wetlab team". iGEM appeared to have a different view of what art and design offered. We worried that few artists or art schools could afford to enter, while the track essentially created a separate competition for them, lessening the value of participation. We continued to advocate our position by email, with Agapakis meeting with iGEM HQ in person. In October 2014, iGEM conceded a cross-track Art and Design Prize with an exhibition space at the jamboree, alongside the Art and Design Track.

Our final Art and Design committee comprised artists Oron Catts (SymbioticA) and Rich Pell (Center for Postnatural History), and designers David Benqué (Royal College of Art) and Ben Hooker (ArtCenter College of Design).

January- April 2014: Wiki, Rules and Soliciting Entries

Our iGEM Art and Design rules (2014)—submitted in January and posted on our wiki page (figure B.1)—dictated that the track teams would have to meet iGEM requirements, except that designing a BioBrick, although recommended, would be optional. Parts-based engineering remains a core principle for iGEM, but demanding that art and design students master both technical and critical skills in one summer is itself a challenge.[1] We decided to accommodate those *doing* synthetic biology, as well as those making work *about* it. We provided background to the track and information on precedents on the wiki, as well as our rules and requirements.

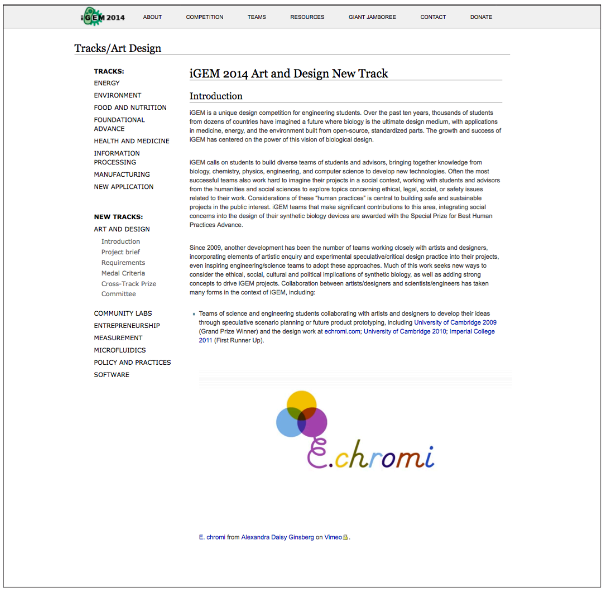


Figure B.1

Screen capture of iGEM Art and Design Wiki. 2014.

1 The young ArtScienceBangalore iGEM 2010 team I helped mentor faced a big challenge, with a single summer to learn bioengineering, reflect on entering iGEM as artists and designers, and then imagine—and build—a BioBrick.

iGEM asked us to solicit entries, so we approached tutors at art and design schools that we thought would be interested. While the track was intended to make iGEM "inclusive", would participation really benefit students? Most art and design schools would balk at spending up to $50,000 for a few select students to enter a genetic engineering competition. Schools would likely have had to commit far earlier to seek special funding for this unusual activity. What justified looking at synthetic biology specifically within the context of iGEM, whether doing wet lab work or cheaper speculative design, without collaborating directly with an engineering team at less cost? Differences between science/engineering and art/design funding were a fundamental barrier to iGEM's desire for inclusivity; Agapakis and I continued to explain to iGEM that they would need to help to get the track going. With most art and design schools priced out, would engineering teams also dismiss the track, or would they see it as an easy track to win?

To stop the track being sidelined, we tried to encode interdisciplinary collaboration into our requirements (see Chapter 2). We encouraged independent practitioners to seek out teams in the engineering or community lab tracks, essentially pushing the cross-track prize instead of the track (iGEM Art and Design 2014). We sought to discourage engineering teams from equating art with making pictures, or designing fake products to fuel hype, aware of the amplifying force of the media at iGEM.

WHAT WE'RE LOOKING FOR

In principle, we are looking for:

- Thoughtful, critical, investigation using art and design to open up our thinking.
- Collaboration between artists, designers, engineers, scientists, and social scientists.
- Projects that use art and design to consider and explore current and future implications of synthetic biology (including stakeholders, communication, pedagogy, thinking outwards), not designing fake applications that increase hype but do not add value to our understanding.
- Projects that use art and design to innovate around issues of applications, social, cultural, ethical, political, economic and technological implications and applications of synthetic biology, especially related to the scientific aspects of the project, not just visualizing or aestheticizing biological material.
- Actively engaging with the public, communities and stakeholders to open up debate and discussion.
- Asking who will be using synthetic biology, what new laws might be needed, how might it change the way we live?

Excerpt from the iGEM 2014 Art and Design wiki.

In addition to the limited number of track prizes and special cross-track prizes, iGEM awards medals to any eligible team. In our track medal criteria, built from iGEM's standard rubric, gold medallists had to "break new ground and surprise us", they had to "Provoke us to think about synthetic biology and its implications in a novel way". To encourage collaboration, we asked them either to work with an iGEM team in another track, design a BioBrick, or evaluate a creative method used to address ethical or social questions, and explain how it impacted on their scientific work. We were curious about what might emerge that differed from the methods used for teams' compulsory Policy & Practices (formerly Human Practices) contribution.

MEDAL CRITERIA

BRONZE. The following 5 goals must be achieved:

1. Register for iGEM, have a great summer, and attend the Giant Jamboree.
2. Create a team wiki sharing background information, context, inspirations and goals for the project, and documentation of your process and outcomes.
3. Present a poster and talk at the Giant Jamboree.
4. Demonstrate the use of art and design for thoughtful, critical investigation of the current and future implications of synthetic biology.
5. Demonstrate the active engagement of engineers, scientists, members of the public, and other stakeholders as part of your project, during the initiation, development, presentation, and documentation your project.

SILVER. In addition to the bronze medal requirements, a team must:

1. Create a short film about or as part of your project. This video must be sent to the committee and iGEM HQ.

AND at least ONE of the following:

2. Design and execute a workshop or event for a group of people outside of your team.
3. Produce an installation or experiment (does not need to be biological) and document it or recreate it at iGEM (please contact artdesign@igem.org to arrange space for presenting your project before October 1st).

GOLD. In addition to the Bronze and Silver Medal requirements, a team must:

1. Provoke us to think about synthetic biology and its implications in a novel way. We are looking for teams to break new ground and surprise us!

AND at least ONE of the following:

2. Collaborate directly with an iGEM team in another track.
3. Design and document on the Registry of Standard Biological Parts at least one new standard BioBrick Part (teams working with biological materials must adhere to all laboratory safety requirements maintained by iGEM).
4. iGEM projects involve important questions beyond the bench, for example relating to (but not limited to) ethics, sustainability, social justice, safety, security, or intellectual property rights. Describe an approach that your team used to address at least one of these questions. Evaluate your approach, including whether it allowed you to answer your question(s), how it influenced the team's scientific project, and how it might be adapted for others to use (within and beyond iGEM). We encourage thoughtful and creative approaches, and those that draw on past Policy & Practice (formerly Human Practices) activities.

Medal criteria from the iGEM 2014 Art and Design wiki.

For the cross-track prize, we wanted to encourage teams to make artefacts, or collaborate with those who would. We wanted to avoid artists and designers contributing only as graphic designers for engineering teams.

iGEM ART & DESIGN CROSS TRACK PRIZE

The cross-track Art & Design prize recognizes exceptional effort to use methods from art and design to explore the potential applications and implications of synthetic biology. For teams of primarily science and engineering students competing in any of the other tracks to be eligible for the Art & Design Prize, they must demonstrate at least ONE of the following:

- Develop a meaningful long-term collaboration with artists and/or designers, whether they are fellow students, advisors, or other project partners. This relationship can take many forms: run a design brainstorming workshop together, co-host an event where artists and scientists share their work and expertise, involve artists directly with the work in the lab, or any other creative mode of collaboration.
- Present a piece related to your iGEM project in the Art & Design exhibition at the Giant Jamboree. Your piece can be in any media and take any form, from video to sculpture to multimedia installation (but for safety reasons no biological materials please). If you are interested in participating in the exhibition, please email: artdesign@igem.org by October 1st to arrange space for your project.

Cross-track prize criteria from the iGEM 2014 Art and Design wiki.

Summer 2014

We needed five teams to run the track; when registration ended in April, we had six. By the jamboree, three teams switched from our track, and two more joined. Over the summer of 2014, Agapakis liaised with the track teams and those wanting to show work in the “iGEM Art & Design” exhibition at the jamboree.

October 2014: The Giant Jamboree

Judges

As iGEM did not cover costs, our international committee could not attend to judge. We recruited two expert judges who paid their own way: Peter Yeadon, a New York-based designer working with science, and Boston-based artist and design professor Sara Hendren. Since Agapakis was an advisor to the ArtCenter MDP team (from ArtCenter College of Design, Pasadena), she could not judge.

The Track

Evaluating the track was difficult. One of our teams presented a conventional science project: *Resurrection of Vitamin C Synthesis* (UST Beijing iGEM 2014). Two teams, KIT-Kyoto iGEM (2014) and Greensboro Aggies iGEM 2014 (no wiki), made bacteria into a painting tool. Through their project, *E. motion*, KIT-Kyoto’s freshman team wanted to use art to “make science more appealing to everyone”. They made one intriguing work, where fly larvae made patterns, making the “art” themselves (see Chapter 2).

Paris Saclay iGEM (2014), a postgraduate engineering team, grappled with synthetic biology's blurring of the real and artificial in *This Is Not A Lemon*. Surrealist painter Magritte inspired their project about visions of future synthetic food. The team conducted research into philosophy and history of art to inform their project, writing a long essay in the ethics section of their wiki, alongside efforts to make an artificial lemon out of moulded agar jelly and bacteria. They engineered *E. coli* to produce a lemon smell and tried to make bacteria secrete coloured proteins to simulate ripening, with a colour change from green to yellow. But this concept was lost in their presentation, which used a vintage 1950s aesthetic, a game show format, and a rather sexist video promoting their fictional product called "Fastlemon". The judges felt that the art needed editing, adding that the science seemed underdeveloped for a postgraduate team. We were interested to see scientists and engineers addressing philosophical questions *through* science, but the team would have benefited from an art advisor. It transpired that some members had been reluctant to select this track.

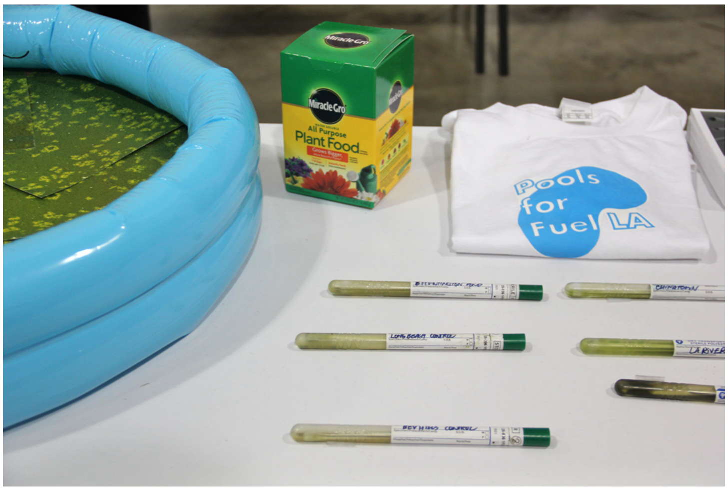


Figure B.2
Car Pools by ArtCenter MDP iGEM 2014.

The ArtCenter MDP iGEM team (2014) presented *Car Pools*, simulating life in a biological utopia of distributed, green technology: LA's oil derricks would be made obsolete as its 43,000 swimming pools would be transformed into algal biofuel ponds. The students addressed synthetic biology speculatively at both user and infrastructural scale. However, the project lacked science: they collected algal samples around LA, grew and tended them in swimming-pool-shaped containers, but did not go further (figure B.2). Meeting algae experts and brewers, or visiting algae farms, would have advanced their thinking. Due to cost, the ArtCenter team was represented at iGEM by just two of their graduate team; the other students did not get to benefit from experiencing the jamboree.

Agapakis and I had warned iGEM HQ that it would be hard to judge art and design by rubric. But we discovered during judging that amongst our specialist and assigned judges we only had one scientist who could fully evaluate the science of the four engineering teams. Our judges agreed that a team should not win by ticking boxes alone. Quality mattered: iGEM should hold all tracks to the same high level. The ArtCenter project was novel, whereas Paris Saclay tackled a popular question; both lacked crucial elements. We wanted to reward work done, but we were wary that endorsing an incomplete project would influence future work. The judges wanted to withhold the track prize. Encouraged by iGEM to award it, we chose ArtCenter. The team had considered their contribution to iGEM as artists and designers; their work synthesised fiction, critique, and experimental design research. Their experiments were basic, but the project opened up a broad discussion around distributed energy sources, private property as infrastructure, and collective action. This approach could be used to cultivate multiple publics, including scientific, policy, and stakeholder communities.

The Prize

In 2014, a new rule restricted teams so that they could only nominate themselves for two cross-track awards. Thirty-one teams opted to enter the "Best Supporting Art & Design Award". Their texts justifying their entry provide insight into the global reach and variety of practices. Some understood our requirements to use art and design to consider implications of synthetic biology; others used them as communication tools (for examples, see table on following page).

The final exhibition (figure B.3-4) contained posters and objects and films made from twelve teams. Despite Agapakis's and my requests to iGEM for a dedicated exhibition space, we had to use conventional poster/table furniture in a corner of the vast poster session in Boston's Hynes Convention Center. The teams' displays amassed iGEM's art and design activity into a single space for the first time, while revealing the diverse interpretation of our brief.

The Art and Design Prize revealed higher-quality work than in the track. For example, the StanfordBrownSpelman iGEM team (2014), supervised by NASA astrobiologist Lynne Rothschild, used a design object to direct their research. For their project, *Towards a Biodegradable UAV* (unmanned aerial vehicle), the team developed a bioplastic that could be moulded and 3D-printed. The plastic was made by transferring the acetylation machinery from *Pseudomonas fluorescens* into *Gluconacetobacter hansenii.* They made a non-toxic waterproof coating from wasp proteins and bacterial wax esters to cover a prototype drone (figure B.5) grown from mycelium by mushroom packaging firm Ecovative, and designed by Eli Block, a team member from Brown and Rhode Island School of Design. I enjoyed the provocation of a biodegradable drone, but one judge marked it down for using a commercially available material in a traditional design, commenting that their composite would underperform compared to materials already used in UAVs.

Figure B.3
The "iGEM Art & Design" exhibition at the 2014 jamboree gave space for teams in the track or prize to show their work.

Figure B.4
Some art and design entries were illustrative, like this cartoon by Technion Israel iGEM 2014 team.

Berlin

We teamed up with representatives from the local and international bioarts and biohacker scene and conducted two workshops for people without science background. The first workshop was a speculative design workshop and resulted in interactions addressing current debated SynBio issues. In the second art workshop, we collaborated with the Artlaboratory Berlin and Howard Boland from the c-Lab (UK) and held an synthetic biology workshop together for the public and interested bioartists. http://2014.igem.org/Team:Berlin/Workshop

BGU_Israel

We have invented the “Inner Doctor” brand and used animated short video to show the potential of our treatment. Before the branding it was very difficult to accessible the controversial field of genetic engineering especially if it is intending to human patient as a medicin. We was amazed to realize that the moment we have stopped using the biological terms and introduced the nucleic acids ass a microscopic doctor which cure the cell. http://2014.igem.org/Team:BGU_Israel/Human_Practice/Spread_The_Word

Edinburgh

An educational video about our project submitted to BIO-FICTION Science Art and Film Festival describing the aims and goals of mixed consortia and the advantages of Metabolic Wiring over quorum sensing. Also a living art piece done by Frazer Salter symbolising future Synthetic Biology possibilities. Inspired by the idea of mixed consortia working together he portrayed a fusion between nature and technology through the use of a biological component in the tree and technological part in the boat. http://2014.igem.org/Team:Edinburgh/outreach/

Exeter

By personifying our *E.coli* as a character, TNTony, we were able to make the project more attractive and interesting to a younger audience, whilst still maintaining the in depth aspects of our project. We also worked with an artist to create other TNTony characters “hopefully reflecting the changing and engaging world of synthetic biology and the contributions that all audiences, young and old, can make. http://2014.igem.org/Team:Exeter

HUST-China

Our team designed really beautiful wiki, logo and T-shirt with a consistent ancient China style. http://2014.igem.org/Team:HUST-China

IIT_Delhi

For this prize, We collaborated with Game Designer Mr. Karan Varshney, he made a multi-platform (android, PC, linux, MAC) game named “ECO COLI” based on the project of our theme. Further we collaborated with INK STORMS ART (a Delhi based artists association) and attended their events and discussed about our project also the associations’s founder wrote poems for our project to showcase us artistically. http://2014.igem.org/Team:IIT_Delhi/Achievements

Imperial

Since brainstorming we collaborated with artists from the RCA in order to get inspiration for our project. Since we are working with bacterial cellulose, an exciting biomaterial, and explore its functionalisation with proteins, we are using the material in order to create accessories and garments which are to be colored by attaching chromoproteins. As part of this endeavour we have been colaborating with fashion designers and artists. http://2014.igem.org/Team:Imperial/Art_and_Design

Lethbridge

The University of Lethbridge iGEM team created works of art inspired by synthetic biology for our annual charity dinner. We also painted a mural in one of the main tunnel passageways at the University. This tunnel experiences high student traffic and serves as a conversation starter about synthetic biology. We have received a lot of positive feedback about our mural, and we hope it will inspire others to pursue synthetic biology for years to come.

http://2014.igem.org/Team:Lethbridge/outreach

Paris_Bettencourt

Our design contribution was to place the project in a social context. Our research has a direct impact on the human being through the creation of a probiotic deodorant. Thus, we want to envision what the evolution of the perception of body odor will be if such a product was successfully developed. We designed a new product and a video, we described the social ecosystem around this product in the near future. We worked with odor specialists and philosophers to refine this study. http://2014.igem.org/Team:Paris_Bettencourt/Project/Art

Saarland

The graphic design of our wiki, poster and presentation is handmade creative artwork by our team. Most of the graphics were drawn by hand, scanned and digitally edited. Our concept is inspired by a famous movie series and combines it with characteristics of an intresting, real-life animal. This enables the promotion of biotechnological methods and largely unknown, but fascinating animals. http://2014.igem.org/Team:Saarland

StanfordBrownSpelman

We prototyped and built components of a UAV using biomaterials like mycelium, cellulose, and bioplastics. We have created a photo collage and plan an art exhibit at the Jamboree if we get space. http://2014.igem.org/Team:StanfordBrownSpelman/Building_The_Drone

Tec-Monterrey

We formed an interdisciplinary team that worked with us since summer and as a result, they managed to design a Wiki that could rely on the simplicity for the user. The main page has an animated video that explains in a very simple way the nature of the project. With these elements, any people with basic knowledge of biology can understand what we are doing in our project as well as its impact and importance for the community. http://2014.igem.org/Team:Tec-Monterrey

Technion-Israel

Trying to explain a scientific idea to the public is not an easy thing to do, no matter in which language you choose to use. That’s why we are strong believers in the saying: “a picture is worth a thousand words”. All along our project we tried to enhance our scientific explanations through art. A great effort was made to simplify our “Safie” project so every person out there could relate to it through the language of art.” http://2014.igem.org/Team:Technion-Israel/HP#art

UCL

Our Art efforts culminated in a public exhibition and industry attended opening night. We collaborated with Central St Martins to make hand woven visualisations of our biobricks in future design projects. We made a concept art short film #UncolourMeCurious to raise awareness which has been shortlisted for the biofiction film festival. Worked with Bio Artists; Linden Gledhill (microscopic photographer), Natsai Audrey (bacterial dye synthesis) and The Slade (pigment library) for the exhibit. http://2014.igem.org/Team:UCL/Humans/Story

UESTC-China

There should be a better way to sell the idea of synthetic biology instead of reading item by item from textbooks. Pandas are beloved animals. Sichuan is the hometown of panda. So we used pandas as our mascot, made our questionnaires, posters, gifts and others designed in the same theme. That made our project more attractive. Meanwhile, our panda was a star in the movie which promoted synthetic biology online. We hoped all people like synthetic biology, as like pandas. http://2014.igem.org/Team:UESTC-China/Art

Uppsala

We have chosen to characterise our project with a specific theme to make us and our project easily recognizable. Since our bacteria is designed to; seek, target and destroy pathogens, the characterstic of our project is obviously in military theme. The military theme is without a doubt linked to objects and/or images of camouflage patterns, sniper sights and hand grenades. These are typical symbols that we have used throughout the marketing of our project and are unmistakably associated with us. http://2014.igem.org/Team:Uppsala

USTC-China

C. imager is a photographic system based on Caulobacter crescentus. Using this product, colorful pictures can be exhibited on the media with proper regulation. This design can be applied in many fields to achieve the combination of science with art and will not only improve biological technology and but show fantasy of nature. http://2014.igem.org/Team:USTC-China/project/results

Valencia_Biocampus

The whole wiki has been illustrated by the watercolor technique by one of us, Paula Villaescusa (see sub-section drawing); she has also created an allegorical diverse ecology scenario landscape for our HP report focusing on Intellectual Property; we have shot two video clips to explain our project (including a YMCA parody) and set in place a new musical concept at the interphase between genetics and integral serialism: epigenetic musical interpretation of one of our BioBricks. http://2014.igem.org/Team:Valencia_Biocampus/ArtAndMore

Excerpts from teams’ Art and Design Prize entry statements.

Figure B.5
Eli Block, a designer on the StanfordBrownSpelman iGEM team 2014 worked on this biodegradable drone with mushroom-packaging manufacturers Ecovative. It received international press.

By comparison, the design work by the postgraduate Paris Bettencourt iGEM team (2014) from the Centre Recherches Interdisciplinaires (CRI) was original in many ways. Designers Marguerite Benony (who was also in the 2013 team) and Marianne Cardon were funded and worked from the laboratory the entire summer. Design was present throughout the engineering project, *The Smell of Us*. The team created a playful BioBrick palette of smells from banana to butter, and designed bacteria to counter distinctive body odours produced by the skin's microbiome. The designers speculated on future products: their installation illustrated a fictional probiotic cosmetic company with bottles of donated prized body odours, paired with plaster casts of noses and armpits (figure B.6). But their most transformative contribution was, in fact, graphic design. They created a provocative and humorous visual identity for the team's science presentation with baroque nudes, splashing naked flesh across the dry scientific presentations that normally abstract away life (figure 2.9). The team and instructors all said that they learnt a lot from the collaboration; Benony is now doing her PhD at the CRI.

Figure B.6
The Smell of Us: the Paris Bettencourt iGEM 2014 team's designers created a speculative future odour shop, illustrated with plaster cast armpits and bottles of body odour, and a timeline, in the "iGEM Art & Design" exhibition space.

Some innovative art and design work was not exhibited and could not be judged, as the teams didn't nominate themselves. These teams told me that they didn't know about the prize, or that iGEM's new restriction limiting self-nomination for special prizes meant that they prioritised being judged on their science. The University of Sheffield iGEM team (2014) showed a physical prototype for the *Fatberglar*, an under-sink bioreactor that would contain engineered organisms to digest fats and hair before they clog up the sewage system (figure 2.10). The Marburg iGEM team (2014) worked with visually impaired students to design tools for those without sight, like converting visual data into sounds. UCLA iGEM (2014) collaborated with their university's Art|Sci Center, staging an exhibition and talks in Los Angeles. One team from the Community Lab Track was outstanding. The first museum to enter iGEM, the Tech Museum of Innovation iGEM team (2014) from San Jose, CA, led by Romie Littrell, created *e.pixel*, an exhibit that let visitors create and analyse pixels made from multi-coloured bacteria (figure B.7), now part of the *BioDesign Studio*, the museum's permanent exhibit introducing biological engineering. Agapakis had emailed the Community Lab teams to ask them to participate in the exhibition; still, Littrell told me he didn't know about the prize. By contrast, Imperial College London iGEM (2014) had nominated their work with designer Victoria Geaney (figure B.8), who used the team's cellulose to make a jacket, an approach pioneered by Suzanne Lee in her "Biocouture" work (2010). But I thought that their engineering work was more interesting: a prototype cellulose filter membrane, which has since become a spin-off company from Imperial College (figure B.9).

Figure B.7
The Tech Museum iGEM 2014 team's entry, *e.pixel*, was an interactive museum display using synthetic biology to involve visitors in making and analysing multi-coloured bacteria.

Figure B.8
The Imperial College London iGEM 2014 team nominated fashion designer Victoria Geaney's cellulose jacket for the iGEM Art and Design Prize.

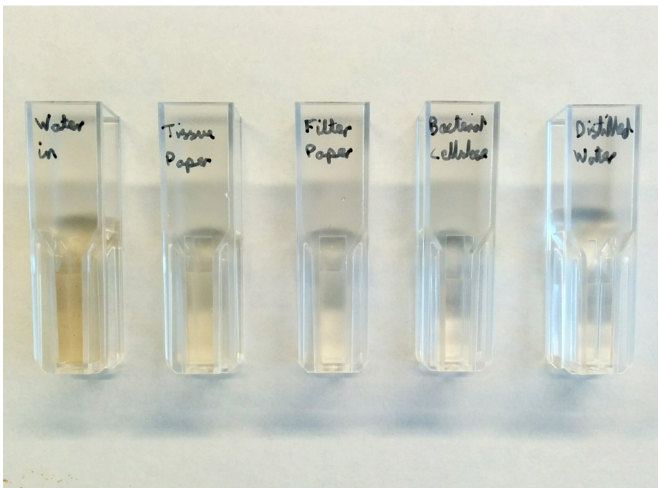


Figure B.9
Imperial College London iGEM 2014's project, *Aqualose*, engineered customisable ultrafiltration (UF) membranes made from cellulose, shown here filtering a sample of water contaminated with solids from the college lawn. The team didn't consider this novel industrial design for entry in the Art and Design Prize.

It was only at the jamboree that I realised that iGEM's judging system precluded the two specialist Art and Design Track judges and myself from voting on the Art and Design Prize, upon which my participation had been contingent.[2] When I asked judges who were evaluating engineering teams for this prize, many told me that despite our rubric they didn't feel qualified or trained to vote on Art and Design, so had left the voting box blank. After a series of difficult conversations with iGEM HQ, the specialist judges were allowed to cast their vote. Despite the trouble caused with iGEM HQ by arguing for this accession during the busy jamboree, I was determined that teams' art and design efforts were respected to the same level as engineering.

JUDGING RUBRIC

How good is the project installation in the art & design exhibition space?

1. Compelling and extremely well done. Excellent work that tells a great story or asks new questions.
2. Well crafted and arranged for effective presentation.
3. Pretty good.
4. Needs improvement.
5. Just bad.
6. Confusing, poorly made, boring. Very bad.

How well does the project address potential applications and implications of synthetic biology?

1. Thoughtfully and thoroughly engaged, asks new questions that should be considered by synthetic biology.
2. Well considered.
3. Addressed but not well investigated.
4. Addressed but not considered at all.
5. Barely mentioned.
6. Not at all.

How creative and original is the team's overall art/design work?

1. Completely unexpected; breaks new ground.
2. Very original.
3. Has some innovative aspects.
4. Single innovative idea.
5. Fairly Standard.
6. Unoriginal.

How well did the team engage in collaboration with people outside their primary fields?

1. Extremely collaborative throughout the project, multidisciplinary team or long-term relationship with outside sources, developed new mode(s) of practice.
2. Worked closely with other researchers for part of the project.
3. Held a workshop or helped another team directly.
4. Consulted with advisors and students from other disciplines.
5. Read widely in many fields.
6. Didn't talk to anyone outside the team.

"Best Supporting Art and Design" Prize judging rubric.

2 The larger squad of Policy and Practices judges encountered the same problem with their cross-track prize.

iGEM Feedback Session

We ran a feedback session on the final day of iGEM, asking attendees what should happen next. The Paris Saclay and KIT-Kyoto teams and their advisors explained that they found the track a strange segregation of art and design. Students were left confused by the experience. They had either not understood the track, or were not trained in art and design.[3]

November 2014: Debrief Report

I offered to iterate our efforts in 2015. In a nine-page report I submitted to iGEM HQ in November 2014, I advocated that iGEM must help develop funding streams if they wanted art and design schools to enter, explaining that this was the greatest obstacle to their dream of inclusivity. I suggested an annual theme, such as "Ecology", could facilitate schools to identify sponsors. I recommended improving the judging rubric, emphasising art and design as a method to explore contexts and implications, rather than seeing art as an application. I endorsed the cross-competition prize, but not the track, concluding that artists and designers piggy-backing on engineering teams was still the best route. I suggested developing an online platform to match art and design schools with teams, aggregate and archive events and projects, and highlight the best work. Gathering a body of work could help further an emerging network and be used by schools to solicit funding.

iGEM valued art and design so much that they wanted to elevate it, but my expertise was less valuable to them. Agapakis was less concerned than I was. We share many ideas, but although Agapakis was calling herself a designer at iGEM (and others referred to her as an artist), she was a respected insider with a synthetic biology PhD. I remained an outsider.

Agapakis and I had identified what made for good collaborations. I summarised in my report that success came when teams touched on some or all of the following areas, as the Paris Bettencourt iGEM 2014 team had:

1. Product: using design to investigate what a product that incorporates the biotechnology could be, whether near future or speculative (imagining future deodorant shop).
2. Research: using design for project research, P&P research, or innovating research in other ways (e.g. research into recipes of ancient biological deodorants).
3. Communication: more traditional use of design, but still great when it is innovative and transforms design itself (e.g. the Bettencourt use of classical nude paintings, bringing the human body full frontal into an engineering competition was amazing).
4. Critique: using design to raise questions about the technology that can help improve it (e.g. speculating on implications of the tech, as they did with their timeline of a synbio smell future).
5. And through collaboration with scientists and engineers, bio design: i.e. synthetic biology itself.

Excerpt from my iGEM Art and Design Debrief Report.

3 Although the jamboree—and much of the field—operates in English, the language barrier may have impeded the understanding of our specialist art and design language.

I still believed that designers could and should politically and socially engage with the iGEM process. I concluded that "I would like to continue working with iGEM, to iterate and build on everything we have achieved so far", but that funding issues and the track's fundamental flaws had to be resolved. In February 2015, iGEM told me I was no longer needed and they were taking art and design at iGEM in a different direction (see Chapter 2).

Appendix C: WISB Residency

This appendix provides more detailed documentation of my planned residency at the Warwick Integrative Synthetic Biology Centre (WISB) to support its evaluation in Chapters 2, 5, and 6.

Description

In 2013, synthetic biologist Orkun Soyer invited me to develop an artist-in-residence position at WISB, the proposed Synthetic Biology Research Centre (SBRC) at Warwick University, which would take a biological approach to synthetic biology (see Chapter 2). Discussions over my role and site visits, including presentations of my work, continued until the centre was funded in October 2014. However, due to differences in vision, in January 2015 I pulled out of the project. While Soyer was eager for me to do critical design research into the synthetic biologists' work, John McCarthy, head of the School of Life Sciences and WISB's director, wanted me to promote synthetic biology's promised benefits. The troubled process provided insight into expectations and modes of interdisciplinary collaboration, positioning critical design in relation to synthetic biology's imaginaries, funding critical design, and navigating public engagement as a critical designer.

Background

I first met synthetic biologist Orkun Soyer in 2009 at an Engineering and Physical Sciences Research Council (EPSRC) synthetic biology funding workshop that I presented at after graduating from my MA. I was intrigued by Soyer's interest in developing an approach to synthetic biology informed by evolution. Soyer, then at the University of Exeter, suggested we collaborate on a public engagement project simulating evolutionary processes; our grant proposal with interaction designer Nicolas Myers was unsuccessful.

Soyer moved to Warwick and in 2013 invited me to create an artist's residency role to explore WISB's vision. The new centre, which he was helping to develop, would design microbial communities and evolvable circuitry instead of adopting synthetic biology's engineering mindset. Soyer was interested in how my critical design approach could contribute to the centre and its research. At Warwick there was potential to connect with the Mead Gallery, the university's contemporary art gallery, and with other disciplines such as creative writing in the English and Comparative Literature Studies department, or Film and Television Studies.

Aims

The project was an opportunity to develop a critical design research position funded by science, building on my experience developing the "Synthetic Aesthetics" residency programme. I hoped to avoid the issues around expectations of public engagement that I was encountering in my ongoing discussions with SynbiCITE about a PhD fellowship (see Appendix D). I saw potential to develop new work through exploration of WISB's alternative vision of a biological paradigm. Experimenting with using critical design in an artist's residency—being asked to respond to others' work, in contrast to my self-directed approach—would provide a rich PhD case study.

Credits and Acknowledgements

- Orkun Soyer and John McCarthy, WISB.

Process

In May 2013, Soyer invited me to give a public talk at Warwick University to introduce my work to its synthetic biologists and other interested parties. In July, I proposed two options for my work to Soyer and McCarthy: a part-time one-year role as "Design Mediator", consulting on public engagement as a studio service at commercial rates, which would fund my independent research; or an academic post as "Artist/Designer in Residence", where I would engage in critical design research over one to three years, producing work for a final exhibition that they would fund. The latter was my preference; Soyer concurred, and we agreed a one-year project. WISB included the role in their first-round SBRC bid that summer to the Biotechnology and Biological Sciences Research Council (BBSRC). Following consultation with Soyer, I wrote in my formal letter of support in July 2013 that I would "interface between the WISB social scientists, UoW Arts Centre and the wider field to bring design and art perspectives into the development of next generation synthetic biology and use these perspectives to engage the general public in the discussion".

I spent five days at Warwick in November 2013, meeting scientists, attending lab meetings, and presenting *Designing for the Sixth Extinction* at Towards Next Generation Synthetic Biology, an international meeting that WISB hosted for prospective collaborators and partners. Reflecting on the heated response to my presentation (discussed in Chapter 5), Soyer suggested I should not be swayed from pursuing my ideas. McCarthy agreed with Soyer, but then suggested I consider promoting synthetic biology and GM's purported benefits.

WISB's first BBSRC funding bid, led by Soyer, was unsuccessful, and the team prepared for the second SBRC funding call in 2014. When I met with McCarthy in May 2014, he suggested a 20% role over five years. I explained that I preferred the shorter project, as previously agreed, to fit my PhD research. McCarthy led and submitted the second SBRC application to the BBSRC in the summer of 2014, and announced WISB's receipt of £10.5m in October 2014. The grant impact statement explains that one way that "societal impact will be maximised" is by "Exploring the role of arts and design, both in the scientific development of SB and its engagement with the public via our formal relationship with our Artist-in-Residence" (McCarthy 2014).

Visiting Warwick in December 2014 to discuss next steps, I met with Sarah Shalgosky, Curator of the Mead Gallery. WISB also set up a meeting for me with Nick Lee, an education researcher, whom they wanted me to work with; there were no scientists present. McCarthy again asked that I make promotional work to show the benefits of synthetic biology. Afterwards, he sent the relevant excerpts of the grant so I could respond with a plan. I was named in a five-year role as "WISB Artist-in-Residence", where I would "supervise and collaborate in public engagement activities and spend at least 3 weeks pa on WISB research and activities". I was concerned: my feedback on my role had not been included, and I was now expected to supervise public engagement work at an academic rate, countering my original proposal. While additional funding was to be provided through outreach and workshop costs, covering exhibitions or artworks, I saw that Soyer and McCarthy held diverging views on art and design's potential role in synthetic biology. Soyer understood my collaboration contributing to research, while McCarthy saw it as a service. I worried that my work would be exploited for promotional purposes, and I would be unable to pursue critical enquiry in the allotted time while also delivering WISB's public engagement. This expectation that I would promote certain visions was obstructing the possibility of researching troubles *within* WISB's vision. Trying to flesh out how this role might avoid public engagement, but still meet their demands, I responded with the following options:

A three-week research project investigating new approaches to the design of biology. Synthetic biology (SB) encompasses the design of novel biological systems and reengineering of existing ones through engineering. Currently, SB focuses on the one-to-one mapping of existing engineering paradigms onto the biological substrate. At WISB, researchers are suggesting the need to develop new paradigms, based on their hypothesis that existing engineering paradigms from man-made systems are ill suited for engineering biological systems.

What would be these novel engineering and design paradigms for achieving SB? Can we amalgamate known engineering principles with biological principles and if so what might the process look like? Should the novel engineering paradigms solely be developed for the purpose of achieving industrial applications? What applications and implications await us in the more biologically-informed version of SB?

In this project, we will explore these questions and the role of experimental forms of design in answering them. Can the methodologies of design provide new ways of thinking about the answers?

The research will involve extensive discussions around the core projects at WISB that aim to establish novel engineering approaches in SB, via participation in meetings of WISB labs, and informal discussion.

OUTPUTS

Either:
1. A custom-designed one-day design methods and discussion workshop exploring themes around futures, innovation, biology and design for the scientific community at WISB, with the working title "Design by Context", for sixteen people. Discussions will be distilled by ADG into a position paper, involving inputs from workshop participants and others if needed. *2 weeks research and development, one-day workshop, four days summarising findings.*

2. Site visits and research (2.5 weeks), followed by one public talk communicating ADG's prior research into SB and reflections on research with WISB. *0.5 weeks development and delivery.*

3. Site visits and research and development of initial concepts for a design project that could be exhibited at Warwick, requiring additional funding from WISB for production. *3 weeks.*

TIMEFRAME

Three-week research engagement including site visits, to include days spent at WISB in 2013-14.

Off-site research conducted at the Royal College of Art, London. Project to be completed in 2015.

Excerpt from proposal for a Design Research Fellow Project at WISB, December 2014.

Nevertheless, I remained uncertain about the project's future. I had spent seven days visiting WISB, but I still felt that my critical design work would conflict with an expectation that the artist or designer's role was to promote synthetic biology, resulting in outcomes that would leave all unsatisfied. In January 2015, I wrote to withdraw from the project.

Appendix D: “Alternative Roads” and *Design Taxonomy*

This appendix provides more detailed documentation of the “Alternative Roads” and *Design Taxonomy* projects to support their evaluation in Chapters 3, 5, and 6.

Description

Two linked projects—“Alternative Roads”, an internal-facing workshop and report for synthetic biologists, and *Design Taxonomy,* a design installation for public exhibition—helped me to identify the imaginary of sustainable abundance. Together, the projects experimentally developed a “critical utopia”: an “alternative better” vision of synthetic biology and mobility. The final title, “Alternative Roads”, was a deliberate counter to the UK’s official vision, the *Synthetic Biology Roadmap* (UK SBRCG 2012). The projects’ structure was an experiment in gaining critical distance from both academic and corporate clients: firstly, the Synthetic Biology Innovation and Commercialisation Industrial Translation Engine (SynbiCITE), the UK’s leading synthetic biology research centre, and secondly, the design news website *Dezeen*, who had been commissioned by the car brand MINI to curate an exhibition on the future of mobility. The two components had separate funding and deliverables, which informed each other:

A: “Alternative Roads” (SynbiCITE)	**B: Design Taxonomy (*Dezeen* for MINI)**
	APRIL 2014: Submit initial research and design ideas for a design installation on synthetic biology and mobility, commissioned by *Dezeen* on behalf of MINI for an exhibition at London Design Festival 2014.
JUNE 2014: Based on initial MINI research on sustainable abundance, biodesign and mobility, design and deliver “Repair Ecologies”, an internal workshop for synthetic biologists at SynbiCITE.	
	JULY - SEPT 2014: From the workshop findings, develop, produce, and exhibit the installation *Design Taxonomy* for exhibition to a design audience at “*Dezeen* and MINI Frontiers”, Design Junction, September 2014.
MARCH 2015: Deliver “Alternative Roads”, an internal working document for SynbiCITE summarising my research, the workshop and findings, and presenting *Design Taxonomy* as a provocation for alternative thinking around future research directions for synthetic biology.	

Background

How might one design a funded collaboration with a synthetic biology centre that enables critical design research? This was the starting point for this project. In July 2013, Minister David Willetts announced £24 million funding to create SynbiCITE, a new Innovation and Knowledge Centre (IKC) at Imperial College London.[1] The Royal College of Art was named as one of the IKC's seventeen university and thirteen industrial partners. Prior to starting my PhD in October 2013, I entered discussions with SynbiCITE co-directors Paul Freemont and Dick Kitney about whether the centre might fund my PhD research via a novel fellowship between Imperial and the RCA. Freemont and Kitney recommended I identify opportunities for collaboration within SynbiCITE's master plan.

Around this time, social scientist Jane Calvert described to me a meeting she had attended with UK synthetic biologists, which included a session where they unsuccessfully tried to brainstorm things to make. I wondered how do synthetic biologists—or any of us—imagine new or better futures beyond what we already know? In advocating the IKC, Kitney identified "translating... research into new products" as a major challenge for the field (C. Smith 2013). The IKC master plan addressed the need to think up applications by including a brainstorming workshop called the "Ideas Lab", for all partners to join in (Kitney & Freemont 2013). It also suggested that the RCA would contribute to early-stage design thinking and product design for new industrial applications. Thus the RCA would provide a more traditional approach to design than developed by the existing relationship between Imperial's synthetic biologists and the RCA's Design Interactions department since 2008.[2] Meanwhile, the master plan tasked social scientists alone with researching Responsible Research and Innovation (RRI). All three areas—the Ideas Lab, early design thinking, and RRI—seemed like potential spaces where I could develop experimental techniques to stimulate alternative visions. As discussions progressed, it became clear that any fellowship funding would be contingent on my assisting with SynbiCITE's public engagement work. I worried this might impact my critical independence. I began the PhD without this funding.

Then, in November 2013, Marcus Fairs, *Dezeen's* founder and editor-in-chief, invited me to participate in an exhibition exploring the future of mobility for MINI.[3] Anticipating that expanding populations and dwindling fossil fuel supplies will threaten future car ownership, MINI, like many car companies, is reimagining itself as a mobility brand. For this marketing exercise six designers were asked to "present an original vision of how people might travel in future", showing "innovative use of both design and technology", while visibly integrating the

1 The funding was from the Engineering and Physical Sciences Research Council (EPSRC), the Biotechnology and Biological Sciences Research Council (BBSRC), and the Technology Strategy Board (TSB).

2 The Centre for Synthetic Biology and Innovation (CSynBI) was founded at Imperial in 2008, with Freemont and Kitney as directors. CSynBI's students and researchers collaborated with the Royal College of Art's Design Interactions master's programme informally from 2008, and formally from 2010. I developed links with CSynBI after graduating from the RCA in 2009. They displayed my work *The Synthetic Kingdom* (2009) in the centre, and used it on the cover of the first synthetic biology textbook (Baldwin 2012).

3 The other designers were Keiichi Matsuda, Lucy McRae, Matthew Plummer-Fernandez, and Dominic Wilcox. Architect Pernilla Ohrstedt designed the exhibition with 3D-scanning specialists ScanLAB creating a digital point cloud mapped onto the physical environment.

new MINI car or brand. *Dezeen* asked me to connect the brief to synthetic biology.[4] For *Dezeen*, a UK-based design news website with global readership, curation was new territory. They acted as curator, project manager, and media partner.

I realised I could use this brief to explore questions raised by SynbiCITE's plans for the Ideas Lab, RRI, and public engagement, while insulating myself from SynbiCITE's marketing needs. I proposed this project to Freemont and Kitney as a case study on a consultancy basis: a design research collaboration that would imagine future applications, materials, processes and concepts, through two workshops and a final internal report. The project would indirectly provide SynbiCITE material for public engagement, as our collaboration would be advertised on the MINI project, but I was not directly communicating their message. Instead of being employed as a research fellow by Imperial, my studio, a limited company, would become a commercial partner of SynbiCITE.

Aims

Developing my critical design techniques, I planned to investigate synthetic biologists' dreams of better, their ideas of sustainable abundance and disruption, and their visioning processes. As my first project with a brand, I could test whether critical work was even possible in a commercially funded project and experiment with the project structure. What protections were needed? Could tailoring deliverables for expert and non-expert audiences improve the work, clarifying intentions and improving interpretation? How might using a less realistic aesthetic language effect interpretation? *Dezeen's* desire to publish work in progress would let me gauge responses to the work, and tweak its messaging.

Credits and Acknowledgements

- Tim Clark, project assistant (June - September 2014);
- Gemma Lord, project research assistant (April - May 2014);
- Marcus Fairs, Ben Hobson and the *Dezeen* team;
- Daniel Werg and MINI team;
- Paul Freemont, Dick Kitney, John Collins, Helen Findon and workshop participants, SynbiCITE;
- Gavin Broad, Jon Turney and Koon-Yang Lee, workshop speakers;
- Cher Potter, workshop facilitator;
- Gordon Addy, Darwin workshop technicians, Simon Bird and RapidForm, all Royal College of Art;
- 2MZ, plinth fabrication;
- Johanna Schmeer, Mariah Wright, Frank Kolkman, and Henrik Nieratschker, fabrication assistance.

4 *Dezeen* had been showing interest in synthetic biology prior to this. They included me in their "*Dezeen* and MINI World Tour" interview series (2013), and they independently ran a week-long special series on speculative design and biology coinciding with the opening of GYO in October 2013. *Dezeen* even has a "synthetic biology" tag to classify biology-related design projects.

Process

April-June 2014: *Dezeen*/MINI Design Submissions

After preliminary research, with help from studio assistant Gemma Lord, I sent my initial concept to *Dezeen* and MINI in April 2014. I proposed an installation that suggested an alternative idea of better car manufacture, a "critical utopia". The work would infer changed notions of ownership, durability, materiality, maintenance, sustainability, and life cycle in a "biological future" through the controlled decay of biological materials. MINI had asked the exhibiting designers to include recognisable car parts in our projects; my concept sketch showed nine car bonnets made of diverse material displayed on stands (figure D.1). I missed a May 2014 visit to MINI's German headquarters with the other designers, but the proposal was approved. In June, I submitted a further image for press release (figure 3.11), and *Dezeen* shot the first of two short films published online, documenting the process.[5]

Figure D.1
"Imagine if car parts were made of biologically produced materials like plastics made from chitin. They may be more sustainable, but it might also mean that they would be less durable. Shorter lifespans, but more sustainable product lifecycles, could emerge. One hood could be shown in the process of controlled decay, presenting a different approach to sustainable manufacturing processes, while suggesting a new direction for synthetic biological innovation." Excerpt and illustration from initial concept submitted to *Dezeen*/MINI in April 2014.

June 2014: "Repair Ecologies" Workshop

Due to scheduling issues at SynbiCITE, the two planned workshops were combined into a one-day event, "Repair Ecologies". The workshop was developed around my installation proposal and

5 The first article with video interview was released on 23 June, mostly focusing on my previous work (Hobson 2014b).

research as prompts to explore how synthetic biologists come up with visions of better futures. I invited participants to question their assumptions and motivations, and to test whether critical design techniques could help them to imagine alternatives. The following invitation was circulated to SynbiCITE members:

> Life is coming to our machines, and our machines are coming to life as synthetic biology proposes the redesign of biology. The smallest of life forms are being turned into living computers and robots as DNA is programmed to detect, record and build, and microbes are redesigned as biological factories that produce materials and fuels. What kind of materials, energy and services will transport us if we live in a biotech revolution? What new infrastructure might we need?
>
> Imagine if car parts were made of biologically produced materials like plastics made from chitin. They may be more sustainable, but it may also make them less durable. Products with shorter life spans, but more sustainable product life cycles could emerge. Controlled decay would offer a different approach to sustainable manufacturing processes, suggesting novel directions for synthetic biological innovation.
>
> This shift in a car's longevity could tie into a changing notion of ownership and maintenance. Our relationship with our cars would no longer focus on the point of purchase, but would rely on a "repair ecology": new parts, locally switched in and out. Distributed manufacturing and repair workshops may customise and modify cars for local environments and ecosystems. A car grown for European roads may diversify from one grown for the hotter weather of desert states, or more humid climates. Cars might evolve to adapt better to new locales, presenting a new way of thinking about customisation.
>
> "Repair Ecologies" is a design workshop to help imagine future applications, processes and concepts for synthetic biology research. Themed around speculations on the future of mobility and synthetic biology, the workshop is designed to inspire synthetic biologists to imagine new and alternative visions for biotechnology.
>
> The workshop will explore issues around lifecycle, materials, infrastructure, use and energy, summarising current research directions in academia and industry and provide provocations to trigger ideas generation around future research directions, materials, new modes of production, future transport usage, and assist speculation on services, laws and user groups. Invited speakers will spark ideas and frame discussion of what 'responsible innovation' might mean in this context.

Excerpt from "Repair Ecologies" workshop invitation.

The volunteer attendees represented a cross-section of SynbiCITE:

- Professor Paul Freemont, Co-Director, SynbiCITE
- Professor Richard Kitney, Co-Director, SynbiCITE
- Dr James Macdonald, Freemont Lab
- Dr Guy-Bart Stan, Stan Group
- Margarita Kopniczky, undergraduate student
- Dr Kirsten Jensen, Research Associate
- Michael Clarke, Masters student
- Inaki Sainz de Murieta, Research Associate
- Christopher Hirst, PhD student
- Dr Robert Dickinson, Senior lecturer, Bioengineering
- Catherine Ainsworth, Research Assistant
- Ben Reeve, PhD student
- John Collins, Commercial Director, SynbiCITE

I brought two facilitators, Cher Potter (Research Fellow and futures expert at the Victoria and Albert Museum), and Timothy Clark (first year Design Interactions MA student), to assist with discussions and documentation.

9.30 - 9.50	MATERIALS LIBRARY & INTRODUCTIONS
9.50-10.15	TALK “Repair Ecologies” Alexandra Daisy Ginsberg.
10.20-11.10	TALK Bio Materials Koon-Yang Lee, University College London.
11.10-11.30	BRAINSTORM Bio Materials Ideas 10 minutes ideas brainstorm + 10 minutes discussion.
11.30-12.00	TALK Disruptive Futures Jon Turney, writer and futures expert.
12.00-12.30	BRAINSTORM Disruptive Biodesign Group ideas + discussion.
1.15-1.45	TALK Wasps Gavin Broad, Senior Curator of *Hymenoptera*, Natural History Museum.
1.45-2.00	BRAINSTORM Collate any further ideas.
2.00-2.20	TALK Bio Road Trip Introduction to design task.
2.20-4.00	DESIGN TASK Bio Road Trip 4 x groups, research materials, organisms, processes and design car.
4.00-4.30	PRESENTATIONS Bio Road Trip 4 x group design presentations.
4.30-5.00	SUM-UP & DISCUSS Identify useful new materials, themes and ideas, next steps.

“Repair Ecologies” workshop programme.

To focus participants on materials, I asked them to bring a biological material with them, without explaining why. On arrival, they added this to our “Materials Library” (figure D.2). We began with my introductory talk, which touched on sustainable vehicle design, biodesign, biomaterials, and biofuels; then I introduced three expert speakers from outside synthetic biology to add new perspectives.

Figure D.2
The Materials Library.

Biomaterials engineer Koon-Yang Lee described his efforts to make biological fibreglass using bacterial cellulose derived from *nata de coco* (a foodstuff made by fermenting coconut water) (figure D.3). Unlike conventional logic in biodesign, which pursues biodegradable materials, Lee wants to design biomaterials that decay very slowly, trapping atmospheric carbon in objects. Futures expert Jon Turney introduced macro issues on sustainability and the history of technology. He explained how in hindsight the lifespan of transformative technologies is often far longer, bringing with him an old technology with a new application: a solar-powered reading light designed for use in developing countries. Gavin Broad, the Natural History Museum's Senior Curator of *Hymenoptera* (wasps) introduced the diversity of wasps' nests, all made from chewed cellulose, and their ovipositors, which have evolved for use in different contexts (figure D.4-5). The synthetic biologists were intrigued by the precise deposition of minerals on the ovipositors' sharp edges.

Figure D.3
Koon-Yang Lee's fibreglass made with bacterial cellulose.

Figure D.4
Variations in wasp nests made from chewed cellulose, photographed on a tour by Gavin Broad of the Natural History Museum's collection, February 2014.

Figure D.5
Wasp ovipositors exhibit precise deposition of minerals on their cutting edges, as Gavin Broad explained.

The morning talks were punctuated with guided brainstorming activities and discussions around definitions of sustainability, disruption, and best practice (see Chapter 3), based on my research questions:

What could synthetic biology contribute to the future of mobility?
What visions do synthetic biologists value for the technology?
What would good/better/ best practice for biological design?
What is ‘ethical’ synthetic biology?
Can we proactively design values and vision for synthetic biology?
Can macro-scale thinking influence DNA design?
Where are the boundaries of what can be designed?

“Repair Ecologies” workshop research questions.

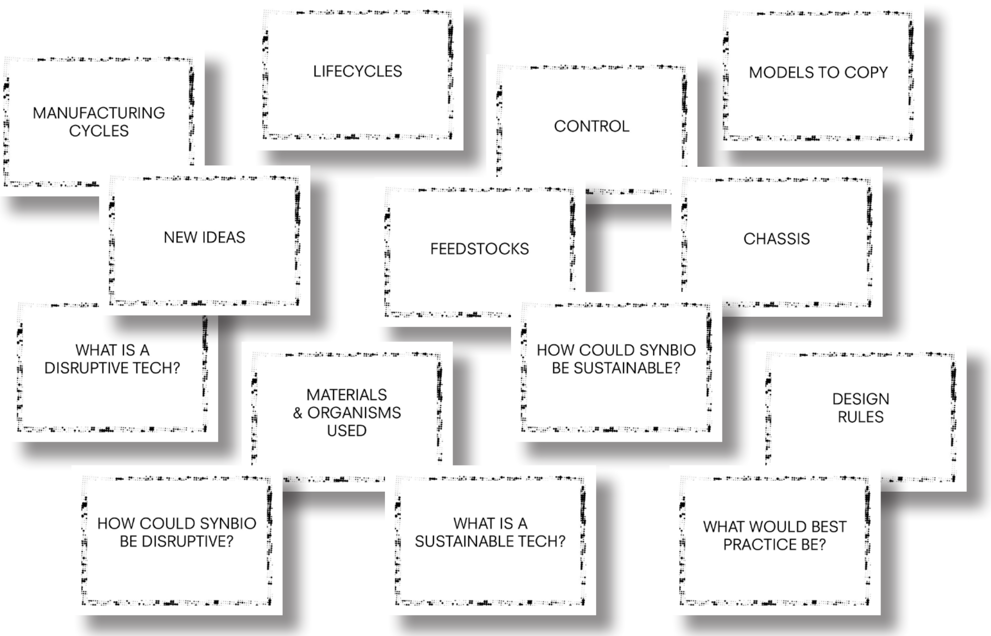


Figure D.6
These prompts were designed to generate data for the research questions. During the discussion sessions, the participants, facilitators, and I circulated the room to add ideas under each title.

Figure D.7
Example of ideas collected during the morning discussion sessions.

The afternoon design task tested whether departing from reality could help synthetic biologists explore what else they could or should make. Ironically referencing synthetic biology entrepreneur J. Craig Venter's bioprospecting efforts, which synthetic biologists would be aware of (Venter is infamous for his microbial sampling trips on his yacht, *Sorcerer II*), I divided the group into four teams, and told them they were off on a fictional bioprospecting road trip to collect organisms from four areas of exceptional natural biodiversity, from the cold Azerbaijani Caucasus to temperate New Zealand (figure D.8).

Reverse engineering visions into reality has been key to synthetic biology's development. So, I informed them that the "biological car" they were travelling in had broken down. To fix their "biocar", they would have to first imagine how it worked. Each team was given a pack containing green cards identifying the fault (figure D.9), including "out of energy", "engine trouble", "crash", and "mutation (diagnosis needed)", and white prompt cards to guide them through the speculation and information to consider. Large worksheets were designed like "roadmaps" of each area, providing context (figure D.8). I asked them to draw on their scientific expertise, and also consider organisms native to the region that they might use to fix their vehicle. I provided reference books more common to a design studio than a laboratory, on topics as varied as art cars to fungi (figure D.10). They could also look to the Materials Library for inspiration, and they had internet access.

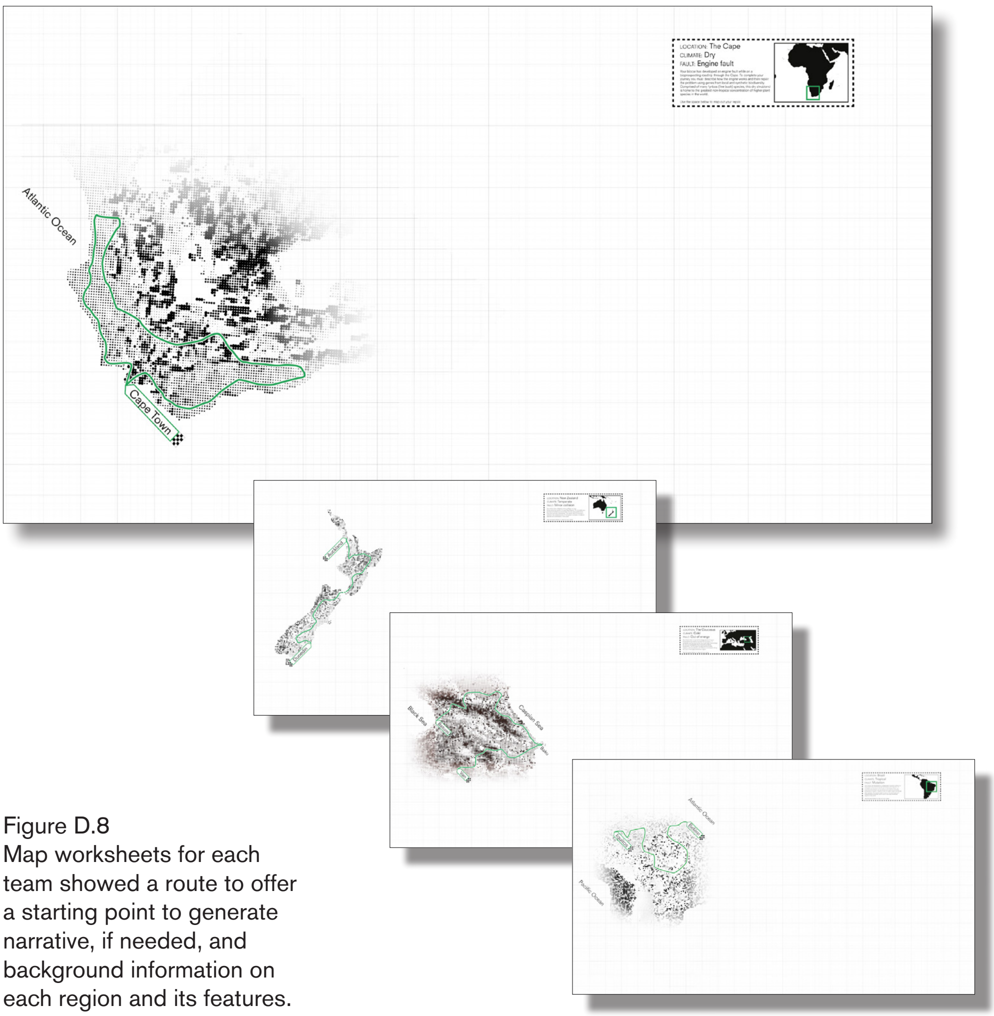


Figure D.8
Map worksheets for each team showed a route to offer a starting point to generate narrative, if needed, and background information on each region and its features.

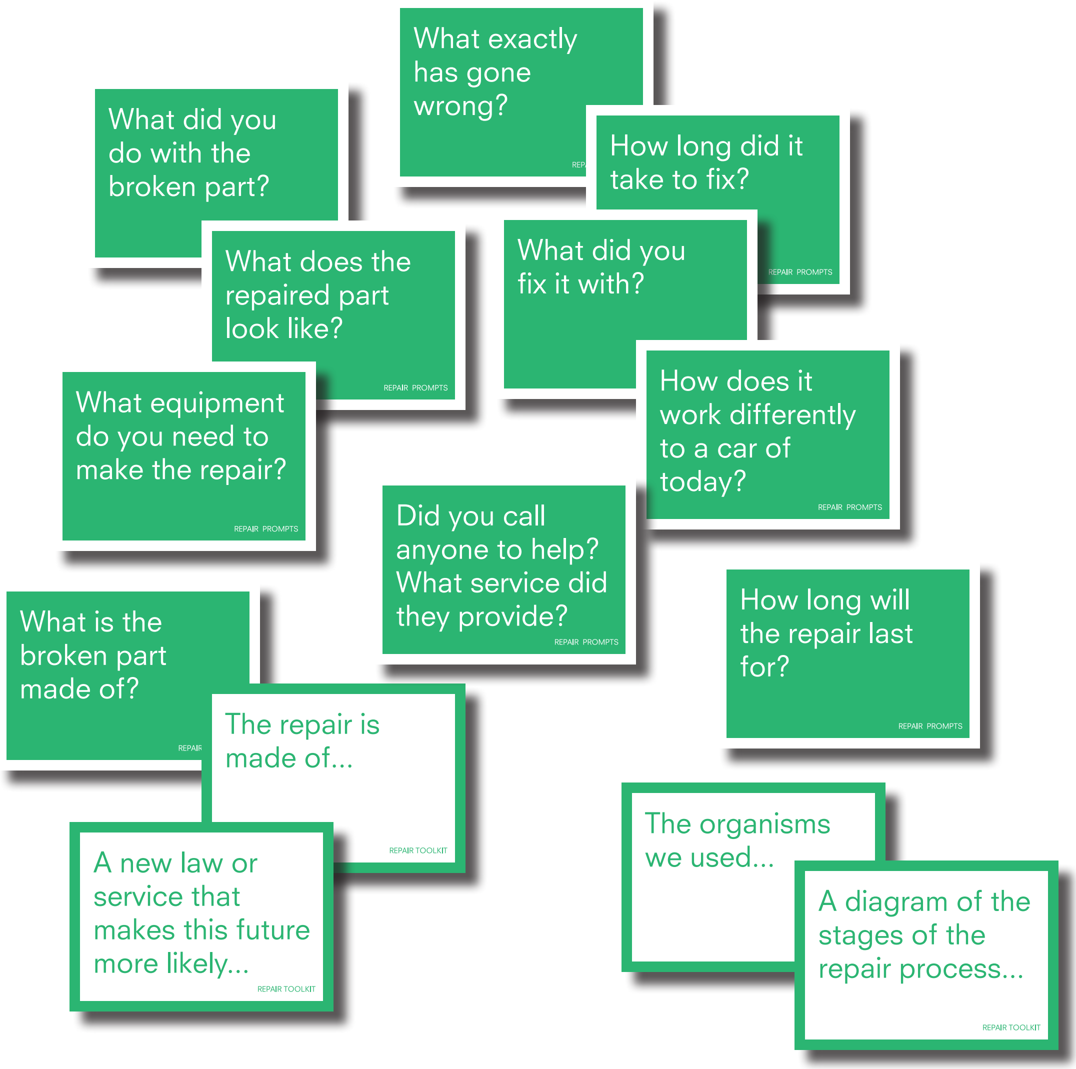


Figure D.9
Prompt card set from the "Bio Road Trip" design fiction exercise. Each group was given a location of their breakdown, a description of the fault, and prompts to resolve their biocar design.

Figure D.10
The workshop library contained a range of reference books for ideas.

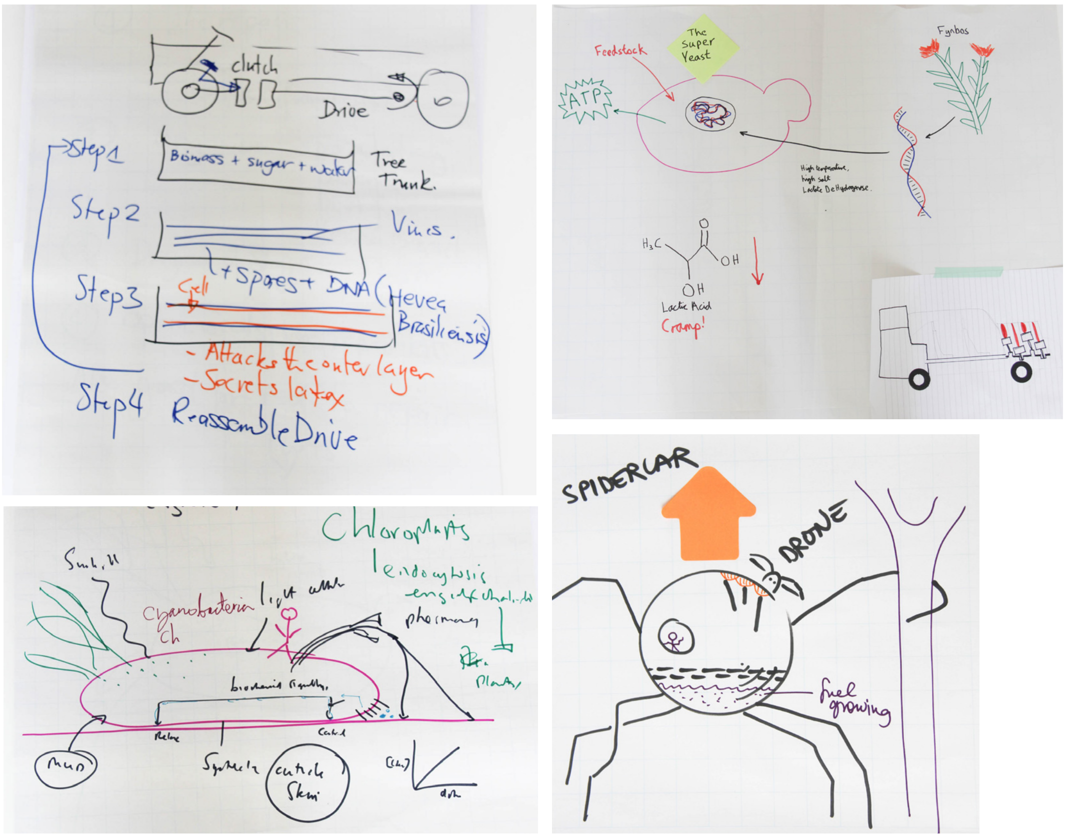


Figure D.11-15
Group work on biocars (see also figures 3.8-9), clockwise from top left: a car with wind-up vine motor, a "muscle" car that gets cramp, a symbiotic "spider" car, and a slow-moving "slug" car.

I explained that their designs could be as close to scientific reality as they wished: I expected tanks of biofuel or biomaterials in the chassis. But despite the discussions about avoiding speculation (see Chapter 5), they imagined wild "slugmobiles" and "muscle" cars (figures D.11-15). Oddly, the exercise enticed them to remake old technologies, such as wind-up motors from living materials, or living components. Some imagined biomaterials that would sense and respond to their environment, even triggering responses in the surrounding ecosystem. By considering the car as a whole to solve how it moved, they uniformly presented visions of reduced mobility. Perhaps they had been influenced by Dunne and Raby's biocar from *United Micro Kingdoms* (2012-13), which I had showed in the morning, asking whether they would accept a car that moves slowly, whose engine needs feeding, and that biodegrades?

The teams responded to the task as problem-solving engineers, although in a playful, even nihilistic way. They may have been influenced by Turney's prognosis: his talk highlighted the lack of real progress in renewable energies. He argued that energy and material scarcity might mean that cars are not in our future. Asking participants to work in a more closely defined space like "fuel" may have yielded more practical results, but the groups' highly imaginative response was intriguing in the context of an industrial centre focused on commercialisation.

While the design task produced wild results, the talks described practical processes: bacterial cellulose production, precision mineral deposition, and aspects of evolutionary diversity, resilience, and robustness. In the closing discussion, participants reflected on how synthetic biology might harness these ideas. Freemont noted that little genomic sequencing had been done in wasps, and asked for a tour of the Natural History Museum's wasp collections. He suggested collaboration with Lee, who that summer advised Imperial's iGEM team on their design of cellulose filtration membranes. Critical design can instigate new connections for innovation.

Just Turney and Lee returned a workshop feedback questionnaire I sent by email. Lee suggested a similar workshop would be useful for imagining composite materials.

June–September 2014: *Design Taxonomy*

After the workshop, I collated the findings to progress my design proposal. I decided to focus on the values that the synthetic biologists had advocated for good design (see Chapter 3), rather than their biocar designs. I began iterating systems, forms and materials (figure D.16-18). Tim Clark assisted me on production from June until September. In July 2014, I sent MINI an updated plan and press images of the first prototypes (figure D.19). Instead of the small number of life-sized bonnets, I proposed an installation with many model cars within a production system. I hoped this might help avoid my "critical utopia" from being taken literally as a prediction or proposal. I wrestled with what level of detail to include, rejecting steering wheels but returning to circular wheels from the first prototypes' stick-and-ball legs (figure D.19).

MINI responded: they still wanted to see a recognisable MINI component. I explained that a car made from biological materials would not look like today's MINI, but reassured them that the cars would not look like any other brand. The MINI identity would be embodied in a playful aesthetic. The idea hinted at the customisation culture of the Mini Moke.

Aesthetic Choices

Design Taxonomy deepened my understanding of aesthetic languages in critical design. To hint that these biological objects would have different properties to mass-produced synthetic plastics, I was looking for a model-making material with a non-uniform appearance. After seeing chitin bioplastics being made in Lee's laboratory, I experimented with DIY protocols to extract chitin from mushrooms. I soon decided that developing a biological material would not only be too time-consuming, it also risked being taken literally. Instead, I invoked biology though the idea of "type specimens" (figure D.20), biological specimens used to represent a species, which I first encountered on Gavin Broad's tour of the Natural History Museum's wasp collections in February 2014. In July and August, material experiments continued to generate unusual finishes to meet my aesthetic aim (figure D.21-26).

The final aesthetic *was* biological, but some visitors thought that on display they looked like food (specifically, cake), rather than alluding to organisms, as intended (figure D.27-8). Clark and I had designed a complex plinth to fill the space (figure D.29-30) to direct the viewer towards a group of small objects in the visually chaotic environment of a design trade fair. The plinth was meant to allude to a diagrammatic plane, highlighting relationships between "generations" of cars (figure D.31), but with the cars on it, pointing in slightly different directions, the connections became harder to see (figure D.32-33). Individual cars became precious, instead of communicating the value of the population as a whole. In a later exhibit at Imperial College London's annual fair, I grouped them on a flat surface under a vitrine like a specimen collection, which worked better (figure D.34-5).

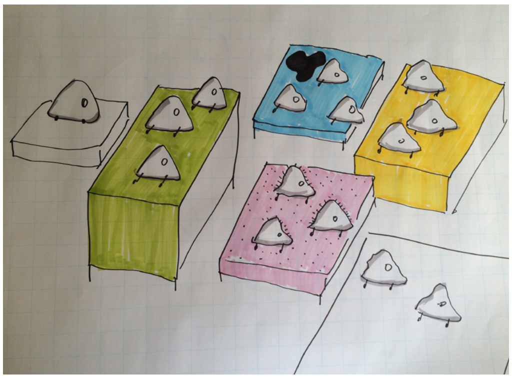


Figure D.16
Design Taxonomy
development sketch, showing "evolution" of car designs, July 2014.

Figure D.17
Design Taxonomy
development sketch, July 2014.

Figure D.18
Design Taxonomy
development sketch, July 2014.

Figure D.19
Prototypes made for press photos, July 2014.

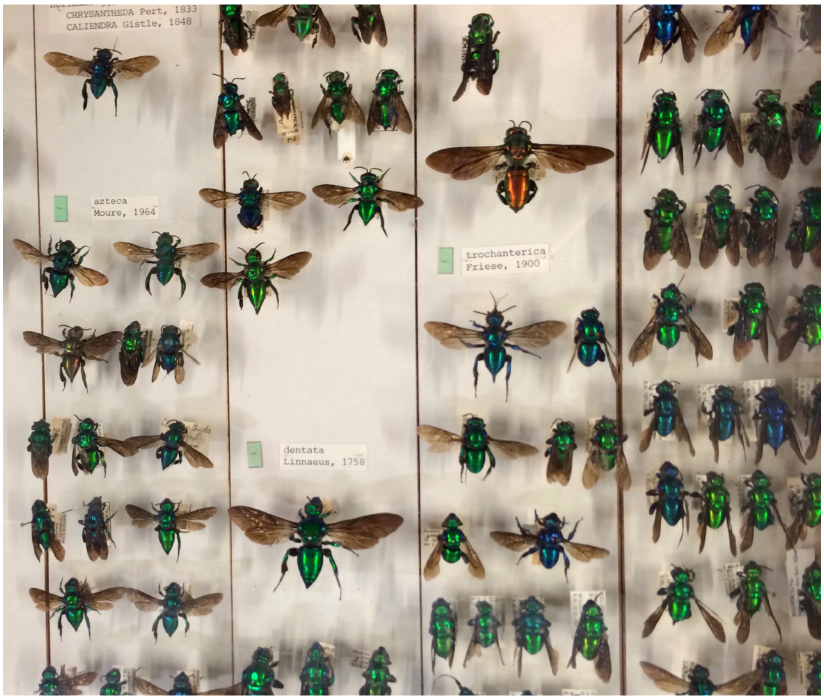


Figure D.20
Wasp type specimens in the Natural History Museum's collections, February 2014.

Figure D.21
After abandoning making biomaterials in July 2014, I began to experiment with using existing ones; such as liquid latex on sheet latex. I decided to mix these kinds of materials with synthetic resins and found objects.

Figure D.22
After these first prototypes in July 2014 I decided to use bolder colours (see D.19) to make the “inherited” traits between design generations more evident and to make the project appear more diagrammatic.

Figure D.23
Material experimentation: we embraced chance in the appearance of the objects; no two cars were identical, August 2014.

Figure D.24
Production details from the workshop, September 2014.

Figure D.25
Production details of model cars, September 2014.

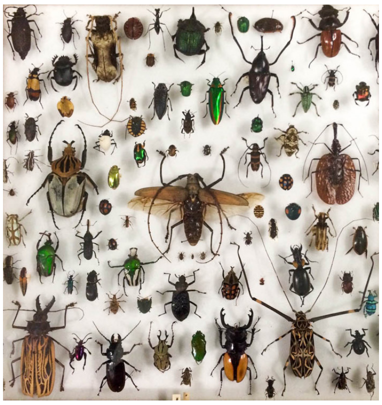


Figure D.26
Insect collections at the Natural History Museum, February 2014.

Figure D.27
Models on the plinth at
"*Dezeen* and MINI Frontiers",
Design Junction, September
2014.

Figure D.28
Models on the plinth at
"*Dezeen* and MINI Frontiers",
September 2014.

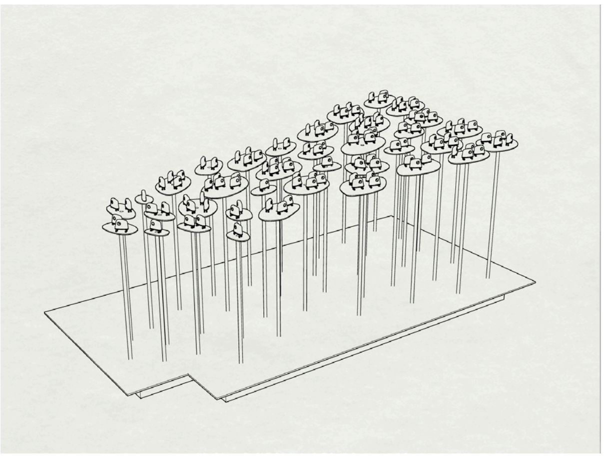


Figure D.29
Plinth design, August 2014.

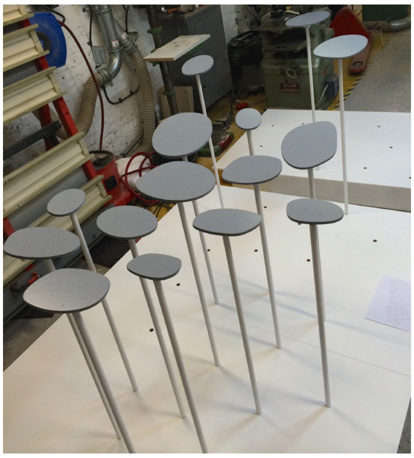


Figure D.30
Plinth development, August
2014.

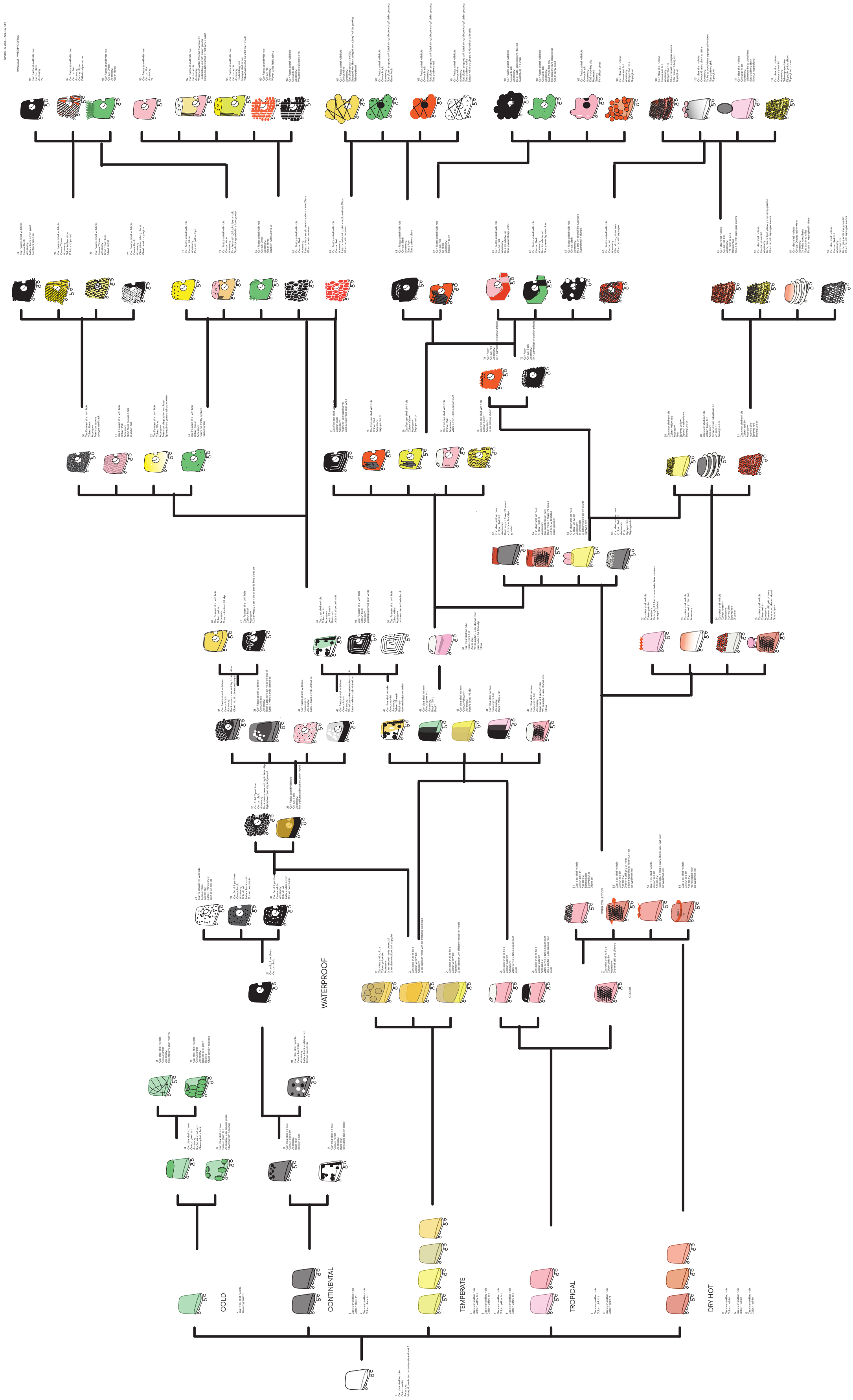


Figure D.31
Working sketch (2014)
to map out features and
“evolution” of car types for
production.

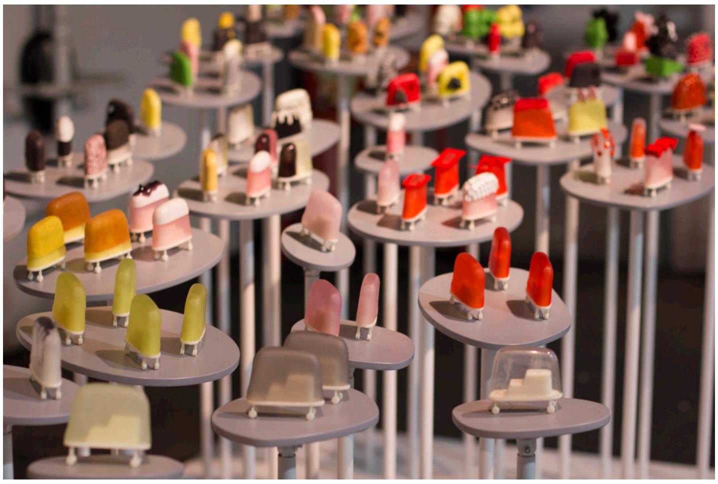


Figure D.32
Installation view of *Design Taxonomy* at "*Dezeen* and MINI Frontiers", September 2014.

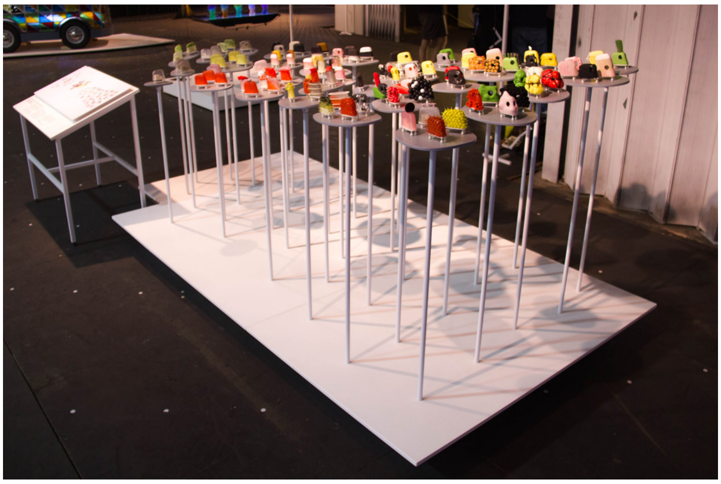


Figure D.33
Installation view at "*Dezeen* and MINI Frontiers", September 2014.

Figure D.34
Revised installation design at the Imperial Festival 2015, Imperial College London, May 2015.

Figure D.35
Revised installation design, May 2015.

Iterating Communication

As discussed in Chapter 5, *Dezeen* and MINI's publishing of work in progress let me see how others were interpreting my articulation of the project via interviews, diagrams and text. This also allowed me to make adjustments, to communicate my intentions more clearly. One example of this came in early July, after the "Frontiers" exhibition press release was issued by MINI's PR agency. Adele Peters, a freelance journalist for *Fast Company*, emailed me the following questions based on my preliminary text:

> 1. Can you give some examples of how a future car might repair itself?
> 2. Are you looking into other ways that cars might evolve, or focused solely on repair?
> 3. How do you think consumers might interact different with these future cars?
> 4. How far in the future do you think cars might be able to repair themselves?
> 5. How is Mini involved in your research? (Peters 2014a).

I realised that my preliminary project text was being misunderstood: I did not intend that cars should repair themselves, or would evolve *themselves*. I asked to postpone the interview until the project was more resolved. *Dezeen* filmed a project video, which they published in September (Hobson 2014c), after which Peters interviewed me, with questions that better represented my intentions:

> 1. What might be the advantages of using biological materials over common car materials? Wouldn't it be better to use durable, long-lasting materials (metal, plastic) that can later be recycled versus frequent manufacturing of less durable materials?
> 2. What are examples of different materials you considered in this project? In something you'd said earlier, you were looking at synthetic materials, but did that shift to natural biological materials?
> 3. What are the advantages of local manufacturing?
> 4. Can you give a few specific examples of how designers might adapt a car for local needs?
> 5. How would repair change with a system like this? Can you explain your illustration that shows 'repair events'? (Peters 2014b).

In the resulting article, "Could future cars be made locally, from local materials?" I was quoted explaining that "The project is not intended as a literal prediction of a desirable future, it's meant to be a provocation about what we might imagine an ideal system" (Peters 2014c). It was useful to see how project texts can be written better to avoid misunderstanding.

Making a critical project for three clients was a balancing act. MINI was using independent designers to promote their brand; SynbiCITE wanted to promote synthetic biology to the public, and *Dezeen* sought interesting projects to attract readers and advertising revenue, without troubling MINI. I created an "alternative better" as critical utopia, developing a playful, lively aesthetic language, while still critiquing present arrangements in both synthetic biology and car manufacturing. This message carried through: at the exhibition Anders Warming, MINI's Head of Design, commented that the ideas around repair were of interest to his team.

The work was shown again at the "MINI Space Festival" at BMW World, Munich, in November 2014), and in 2015 at Imperial College London's annual weekend public festival showcasing their activities (figure D.34-5).

March 2015: "Alternative Roads"

I designed the final 74-page internal document for SynbiCITE in a magazine-like format to differentiate it from the typical scientific paper or report to imply it had a different function (figure 3.15). It was filled with a mix of examples of material innovation by artists, designers, and scientists. It included the project background research, the workshop discussions and outcomes, and documentation of *Design Taxonomy* for discussion. I intended it to be a provocative resource for the synthetic biologists.

I supplied it as a PDF to facilitate sharing within SynbiCITE, issuing it to Freemont, Kitney, and John Collins, SynbiCITE's commercial director, but I am unsure whether it was circulated or read internally. A month later, I showed the report in person to Freemont. A film, the proposed report review session, or even a second workshop, may have had greater impact. Still Collins wanted to distribute the report to their industrial and academic partners.[6]

6 Since it had been agreed as an internal working document, I requested support for getting image permissions, as it was heavily illustrated. Although there was willingness on both sides, this did not come to pass.

Appendix E: *Designing for the Sixth Extinction*

This appendix provides more detailed documentation of the project *Designing for the Sixth Extinction* to support its evaluation in Chapters 4, 5, and 6.

Description

Designing for the Sixth Extinction is a critical design fiction that examines the emergent relationship between the synthetic biology and the conservation communities. It explores the ongoing discussion around synthetic biology's potential contribution to conserving biodiversity. Originally commissioned in 2013 by Science Gallery Dublin for "Grow Your Own... Life After Nature" (GYO), the work uses computer-generated imagery, photography, diagrams, fictional patent texts, and models to explore a future where synthetic biology is used to "infect" nature to save it. The project was well received in the synthetic biology, art, and design communities, receiving a nomination for "Designs of the Year 2015" at London's Design Museum, but it also proved troubling for a few in synthetic biology (see Chapter 5). This feedback informed iterations of the work and its presentation in 2014 and 2015 to increase its fictionality. This process let me reflect on how critical design fictions navigate between reality and imaginaries, and the work's function as it critically renders an imaginary.

Background

In December 2012 I heard about the conference "How will synthetic biology and conservation shape the future of nature?", scheduled for April 2013 by the Wildlife Conservation Society (WCS) to convene the synthetic biology and conservation communities for the first time (see Chapter 4). Fascinated, I emailed the WCS to ask to attend the meeting at the University of Cambridge. By April 2013, my early curatorial research for GYO (see Appendix G) was revealing that synthetic biology's potential impact on conservation was not yet well explored by art or design. Observing the conference discussion informed the project.

Aims

I wanted to explore and reflect on the vision of this group of synthetic biologists and conservationists that synthetic biology could make nature better. The project invited critical examination of synthetic biology's optimistic instrumentalisation of nature: some synthetic biologists see existing biodiversity as a useful resource for parts, but the conservationists were pessimistic about nature's future. I used critical and speculative techniques to elicit previously hidden issues through visualising an imagined world, experimenting with how to represent an entire system in a project. "Placing" synthetic biology into the "wild" provided an aesthetic device to model relationships between synthetic biology and nature. What unexpected conditions might emerge as synthetic biological organisms interact with ecosystems as well as intellectual property and policy systems? I tested using the legal device of the patent to develop narrative and generate insights. The finished work was my largest so far, letting me see how scale could affect the viewer's reading of the fiction.

Credits and Acknowledgements

- Gemma Lord, project assistant (June -September 2014);
- Tommaso Lanza and Tom Mawby, large-format photography and computer-generated imagery;
- Mike Smith Studio, light box fabrication;
- Kent Redford, Nigel Dudley and Rodolfo Dirzo, conservationists;
- Louise Carver and Adrian Jowitt, biodiversity offsetting experts;
- Tom Ellis, SynbiCITE, and Christina Agapakis, UCLA, synthetic biologists;
- Commissioned by Science Gallery Dublin, 2013;
- Financial support for further development from the Istanbul Design Biennial (2014), ZKM | Center for Art and Media Karlsruhe, the Stedelijk Museum, Amsterdam (2015). Support for additional timeline prints from the Design Museum (2015), and the Cooper Hewitt Design Triennial, NYC (2016);
- Editions acquired by Ginkgo Bioworks (2016), and the Zentrum für Kunst und Medientechnologie Karlsruhe (2017).

Process

After the WCS conference I developed the project proposal, which I submitted at the start of June for GYO's invited call for new works (see Appendix G). The curatorial panel commissioned the project in early June. I soon began research and design, completing the project in late October for GYO's opening.

My original proposal had suggested three one-metre-square C-type photographic prints, each showing a different ecosystem containing newly designed organisms and, budget allowing, models. I planned to mix photography and computer-generated imagery, using aesthetic choices to explore new organisms and their relationship with their intended context. I soon reduced my three suggested environments—a forest, an aquatic scene, and the human microbiome—to one. I focused on the forest, adding the patent diagrams, texts, and close-up photographs to imagine this world in more detail. I considered building a digital model of a forest as an enclosed "mescosom", or testing environment, that could be projected like a film in the gallery. After consulting with Tommaso Lanza and Tom Mawby, the project's CGI artists, it was clear that time and budget prevented this.

In June and July, my studio intern Gemma Lord and I developed the narrative to open up issues: who was designing these creatures? Who commissioned them? How would they be disposed of? Whose better was compromised? We mapped out this world's logic (figure E.1), which was the basis for the timeline commissioned in 2014 (see figure 4.5). I debated the project with conservationists, while Lord interviewed biodiversity offsetting experts and began scouting locations around the UK, searching for a pristine-looking forest. Fleshing out the narrative of this world ranged from identifying conservation issues in the UK (to situate the project in "reality") to researching machines, organisms, and patents. In August, we concentrated on the organism designs. I wrote a brief for four different devices and their functions, which we designed through iterating hand and computer sketches (figure E.2) and models. These included features from the project research into existing biodiversity (including fungi, nudibranchs and seeds), as well as designed objects (including Velcro, pumps and pH indicators).

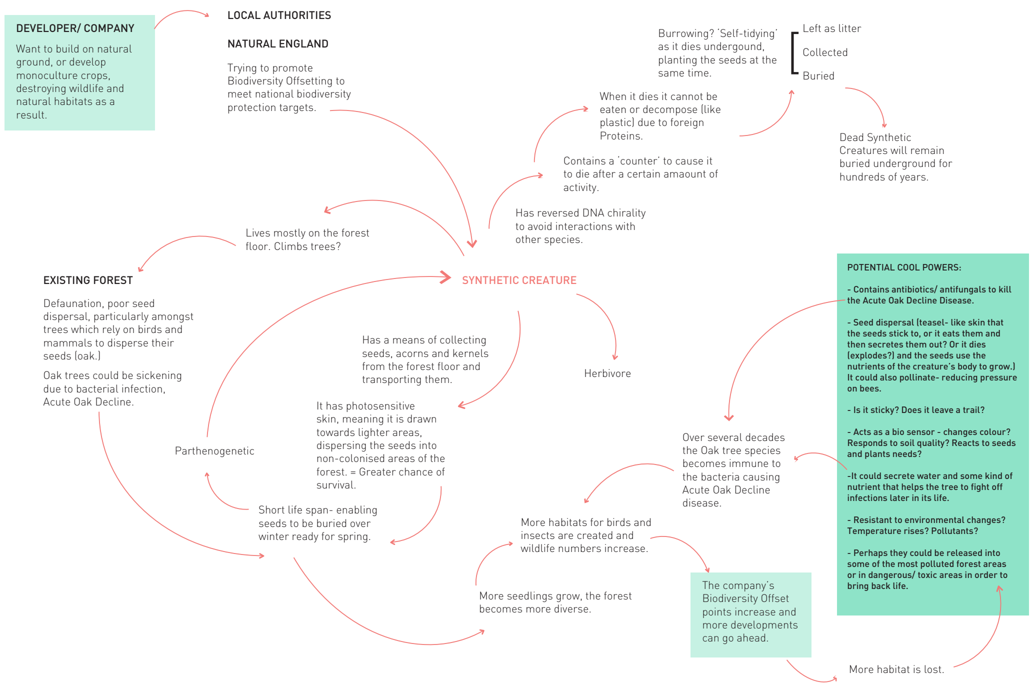


Figure E.1
Map for an unnatural ecosystem, July 2013.

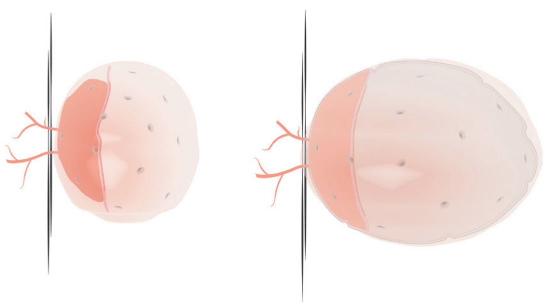


Figure E.2
Development sketch for "Self-inflating Membrane Pump", August 2014.

In early September, we issued boards to the CGI artists, including material finishes (figure E.3), along with line drawings of each device. We went back and forth to develop the look of each device. For instance we rendered the devices with a plasticky finish to make them look more "synthetic". The "Autonomous Seed Disperser" required several iterations to perfect its thick, uniform coating of rubbery spines and wiry hair to trap and release seeds, with eyes and feet invisible to make it look more object- than animal-like (see figure 4.12). At this point, I sent the images and draft project text to Christina Agapakis for feedback on the scientific plausibility.

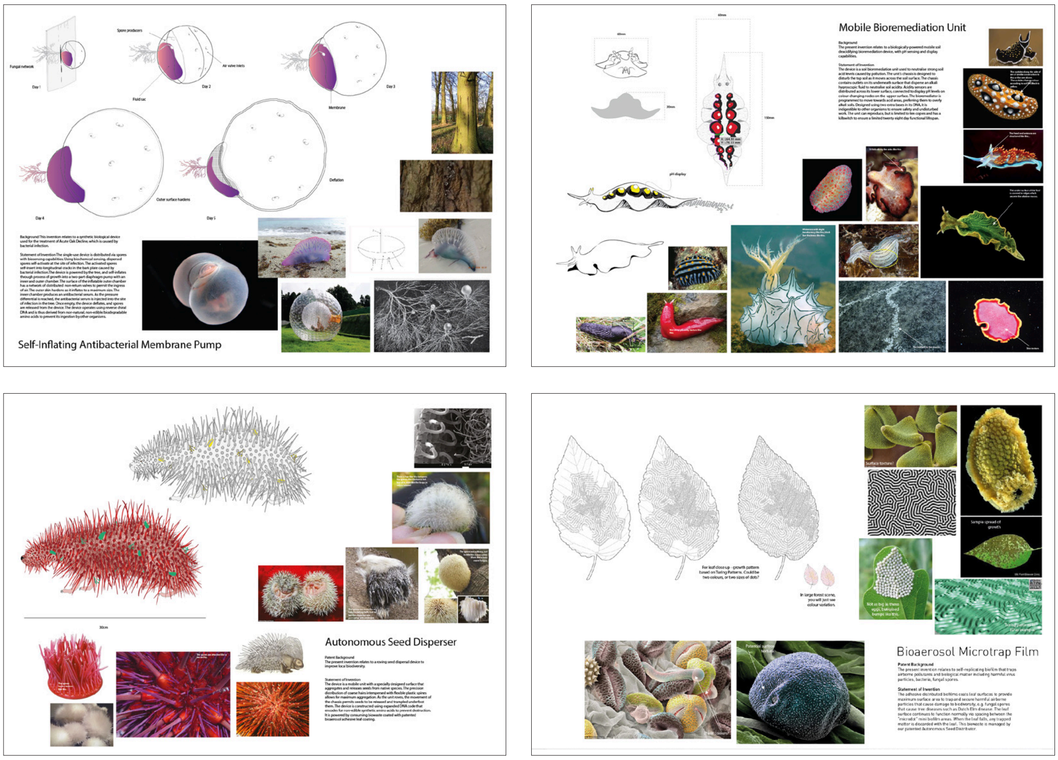


Figure E.3
Material references and diagrams of the four devices, sent to the CGI artists in September 2014.

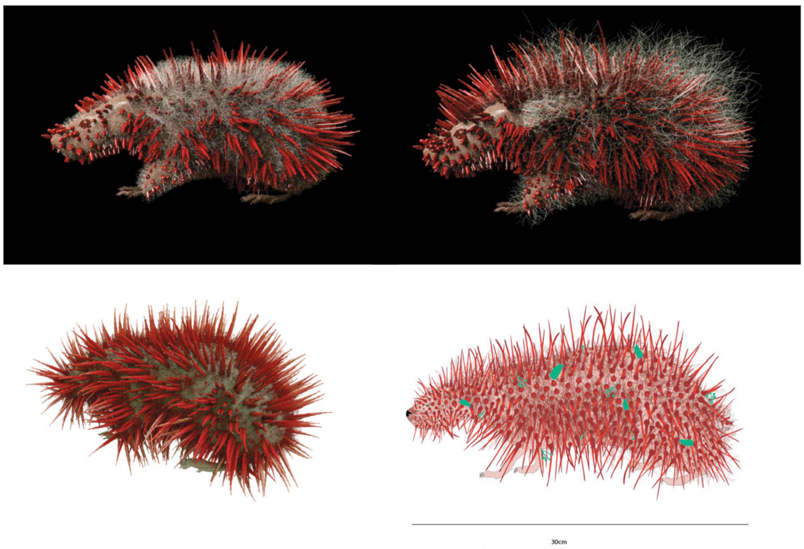


Figure E.4
CGI development of the “Autonomous Seed Disperser”, October 2014.

On location in the woodland in August 2014, I directed the composition of the background plate for the large forest scene, which Lanza and Mawby took. I wanted to evoke the composition of a traditional, grand landscape painting. One contender, figure E.5, while beautiful, lacked depth. The chosen image (see figure 4.4) follows the golden ratio, guiding the viewer across its different focal points where devices are clustered. I took the photographs for the four close-up images of the devices.

Figure E.5
Rejected forest background photograph, August 2014.

In the GYO installation the patent diagrams, patent text excerpts, and close-ups were individually printed, mounted, and placed on plinths under acrylic covers, evoking a museum display (figure E.6-7). Watching people interact with the work, I felt that these artefacts were physically and conceptually too distant from the forest scene. With its simple black glass-less frame, the recessed forest scene alluded to a window puncturing the wall, revealing another world outside. Reflecting on the critique from members of the synthetic biology community (see Chapter 5), I decided to collate and frame the smaller items for "The Future is Not What It Used To Be", the 2014 Istanbul Design Biennial. Its curators wanted to show the research behind the project; we agreed on the timeline format (figure 4.5). I 3D-printed a model "Mobile Bioremediation Unit" too. These successful additions were kept in later presentations of the work. In 2015, I agreed with the Stedelijk Museum and ZKM | Center for Art and Media Karlsruhe to iterate the project. Four model "Mobile Bioremediation Units" were individualised and printed at different sizes and displayed on a light box (figure 5.18). The forest image was printed on film and mounted on a custom-designed LED light box, manufactured by Mike Smith Studios (figure E.8). The glowing forest scene became cinematic; the entire presentation was more immersive. ZKM acquired the complete light-box edition for their collection in 2017, while Ginkgo Bioworks bought the print edition of "Rewilding with Synthetic Biology" for their new Boston foundry in 2016.

Figure E.6
Installation view of unframed patent diagrams and photographs at GYO (2013). In later iterations, the texts and diagrams were integrated, and framed alongside the photographs to increase the fictionality of the display.

Figure E.7
Installation view showing plinths and framed forest print at GYO (2013).

Figure E.8
Installation view of light box edition, with timeline, models, and framed prints, at “Exo-Evolution”, ZKM, Karlsruhe (2015).

Appendix F: "V&A Friday Late: *Synthetic Aesthetics*"

This appendix provides more detailed documentation of the "V&A Friday Late: *Synthetic Aesthetics*" to support its evaluation in Chapter 6.

Description

One Friday each month, the Victoria and Albert Museum (V&A) stays open until 10pm; these "Friday Lates" allow visitors to enjoy the collections with a special roster of events and installations throughout the museum. I led the curation of the April 2014 event, the "V&A Friday Late: *Synthetic Aesthetics*", on the theme of synthetic biology and the design of living things, to launch our co-authored book *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature* (Ginsberg et al. 2014). From January to April 2014, I worked with the Friday Late team and Contemporary Architecture Design and Digital (CADD) curators to programme and produce the event. On the night, over 4000 visitors experienced more than twenty workshops, installations, talks, and screenings (figure F.1). The Friday Late was not without troubles: synthetic biology's sociotechnical imaginaries clashed with my ambition to create an alternative space to explore the design of biology, led by cultural, not political or economic, agendas. Placing living materials in the historical, creative context of the V&A changed the meaning of the works we showed, some of which had earlier appeared in GYO in its more neutral space. I later came to view the Friday Late as a heterotopian space for reflection: a prototype critical imaginary. The project's outcome was an experience that lasted just a few hours; still, this was my largest scale project yet. It expanded my understanding of critical design to include curatorial intervention.

Background

From 2010 to 2014, I was Design Fellow on "Synthetic Aesthetics", an experimental, interdisciplinary project funded in 2009 by the National Science Foundation (NSF) and the Engineering and Physical Sciences Research Council (EPSRC) as scientific research, not as public engagement or art. Our aim was to bring artists and designers into synthetic biology to stimulate new kinds of thinking, research, and critical discussion. Artists and designers were paired with synthetic biologists in six residencies around the world, spending time in both the laboratory and the studio. The project opened up a critical space within synthetic biology and recognised it as a creative practice. A concluding book, edited by Robert Prior, science editor at MIT Press, was itself a collaborative effort between the project's twenty participating artists, designers, synthetic biologists, and social scientists, each with different agendas. Providing an introduction to synthetic biology and questions surrounding the design of living matter, it also documented the residents' projects, from cheese made from human body bacteria to cells used to compute structures. The six projects were used to open up six themes for discussion, from disgust to evolution as a design tool. Our aim was not public engagement for synthetic biology, but to make new things, and to develop new ways of thinking about those things.

In August 2013, I approached Martin Roth, the V&A's director, to ask if the museum might host a talk to launch *Synthetic Aesthetics* in 2014. I wanted to avoid this becoming a public engagement event for synthetic biology, and thought that the V&A could provide the book with a cultural frame. Keen to bring experimentation and science into the museum, in September 2013 Roth suggested a Friday Late dedicated to synthetic biology. Friday Lates are normally curated and produced in house, but due to my expertise on the subject, and staffing changes, I took the lead on content in early 2014, turning this event into a case study for the PhD.

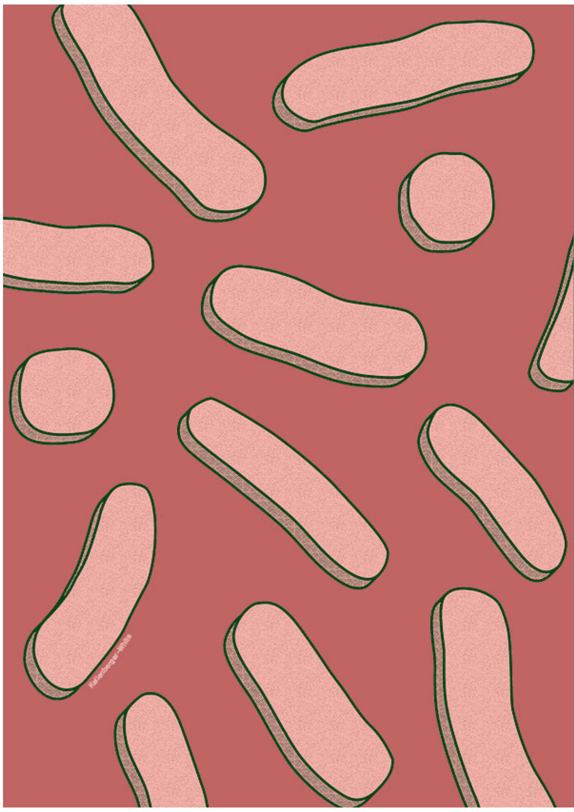
Aims

Friday Lates offer the opportunity for fast experimentation with the museum space, compared to its more conventional curatorial processes. For one evening, we could place synthetic biology in an alternative context, juxtaposing works with the V&A's architecture and collections to generate different meanings. Putting technoscience into this cultural context cast a different light on the work than if we had hosted it over the road at the Science Museum, against its collection of innovations.[1] Launching the book on this scale allowed us to take control of synthetic biology's framing from its vanguard. We could experimentally shift synthetic biology from being seen as a technoscientific venture, to a cultural and creative one.

Credits and Acknowledgements

- Ruth Lie, Polona Dolzan, and Jennifer Zielinska, V&A Friday Late coordinators;
- Corinna Gardner, Rory Hyde and Kieran Long, Contemporary Architecture Design and Digital curators and team;
- Victoria and Albert Museum and bookshop staff;
- Martin Roth, Director of the Victoria and Albert Museum;
- Paul Freemont, Dick Kitney, Kirsten Jensen, and laboratory team, SynbiCITE, Imperial College London;
- MasterCard, Friday Late sponsors;
- EPSRC;
- Robert Prior, Ann Twiselton and team, MIT Press;
- Participating artists, designer, and scientists;
- Jane Calvert, Alistair Elfick, Drew Endy, and Pablo Schyfter, Synthetic Aesthetics;
- Synthetic Aesthetics residents.

1 The Science Museum ran its own synthetic biology-themed late-night event in March 2015.



V&A Presents

FRIDAY LATE with MasterCard

Synthetic Aesthetics

Friday 25 April

18.30 – 22.00

Can we design life itself? The emerging field of synthetic biology crosses the boundary between science and design to manipulate the stuff of life. These new designers use life as a programmable material, creating new organisms with radical applications from materials to machines. Friday Late turns the V&A into a living laboratory, bringing science and design together for one night of events, workshops and installations, each exploring our biological future.

The evening will feature the book launch of *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature* (MIT Press). The book marks an important point in the development of the emerging discipline of synthetic biology, sitting at the intersection between design and science. The book is a result of research funded by the UK's Engineering and Physical Sciences Research Council and the National Science Foundation in the US.

All events are free and places are designated on a first come, first served basis, unless stated otherwise. Filming and photography will be taking place at this event.

Please note, if the Museum reaches capacity we will allow access on a one-in-one-out basis.

#FridayLate

ALL EVENING (18.30 – 21.30)

A
Live Lab
Spotlight Space, Grand Entrance
A functioning synthetic biology lab in the grand entrance places this experimental field front and centre within the historic home of the V&A. Conducting experiments and answering questions from visitors, the lab will be run by synthetic biologists from Imperial College London's EPSRC National Centre for Synthetic Biology & Innovation and SynbiCITE UK Innovation and Knowledge Centre for Synthetic Biology.

B
No Straight Line, No True Circle
Medieval & Renaissance, Room 50a
Young artists from the Royal College of Art's Visual Communication course explore synthetic biology through projections on the walls of the galleries. Each one takes its inspiration from the sculptures around it in a series of site-specific installations.
rca.ac.uk/schools/school-of-communication/visual_communication/

C
Xylinum Cones
Lunchroom
(access via staircase L, follow signs)
What would it mean for our daily lives if we could grow our objects? Xylinum Cones presents an experimental production line that uses bacteria to grow geometric forms. Meet designers Jannis Huelsen and Stefan Schwabe and learn how they are developing a renewable cellulose composite for future industrial uses.
stschwabe.com
jannishuelsen.com

D
Selfmade
Poynter Room, Café
This film tells the story of how biologist Christina Agapakis and smell provocateur Sissel Tolaas produce human cheese. Using swabs from hands, feet, noses and armpits as starter cultures, they produce unique smelling fresh cheeses as unusual portraits of our biological lives.
agapakis.com

E
Grow Your Own Ink
Lunchroom
(access via staircase L, follow signs)
A workshop led by scientist Thomas Landrain and designer Marie-Sarah Adenis showing how to 'grow your own ink'. Try out some of the steps, from the culturing of bacteria to the extraction and purification of biological pigments. Discover the marvellous properties of this one-of-a-kind ink.
lapaillasse.org

F
Bio Logic
Architecture Landing, Room 127
(access via staircase P, follow signs)
Take a trip into the Petri dish, where microchips meet microbes, cells become computers and all is not quite as it seems. *Bio Computation*, a short film by David Benjamin and *Hy-Fi* by The Living demonstrate revolutionary design using new composite building materials at the intersection of synthetic biology, architecture, and computation.
thelivingnewyork.com

G
Zero Park
Bottom of NAL staircase (staircase L)
Where is the line between the natural and the artificial? Somewhere in the midst of Zero Park. Sascha Pohflepp's installation leads you through a synthetic landscape, which poses questions about human agency in natural ecosystems.
pohflepp.com/?q=zeropark

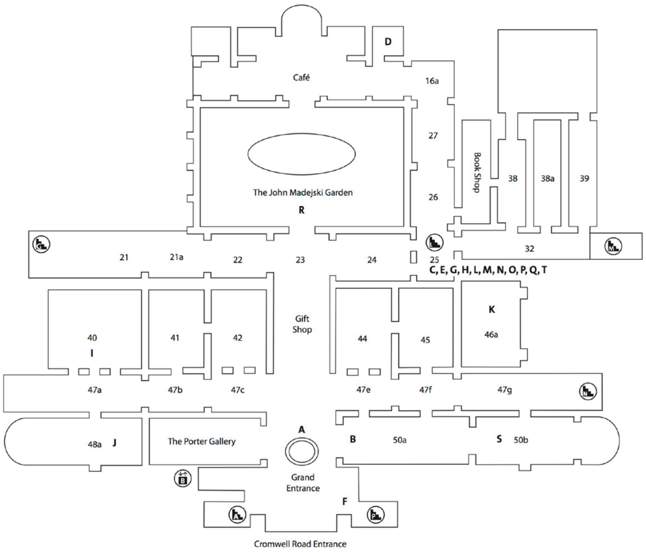
H
Faber Futures:
The Rhizosphere Pigment Lab
Tapestries, Room 94
(access via staircase L)
Bacteria are no longer the bane, but the birth of tapestries! Natsai Audrey Chieza creates a gallery of futurist scarves for which bacteria are the sole agent of colour transformation. In collaboration with John Ward, professor of Structural Molecular Biology, University College London.
natsaiaudrey.tumblr.com

I
Living Things
Fashion, Room 40
Breathing, living, 'second skins' change their shape and appearance as you approach. Silicon-like smart-fabrics show movement and moving patterns. The Cyborg project – led by Carlos Olguin, with Autodesk Research – explores possibilities of new software to create materials with their own 'life'.
autodeskresearch.com

J
The Opera of Prehistoric Creatures
Raphael Gallery, Room 48a
'Lucy', the extinct hominid *Autralopithecus Afarensis*, performs an opera just for you. Marguerite Humeau recreates her vocal tract and cords to bring you the lost voice of this prehistoric creature.
margueritehumeau.com

K
Bacterial DNA Beats
Cast Courts, Room 46a
Can we imagine what it sounds like inside the molecular structure of a DNA helix? This composition is inspired by theoretical speculation on bacteria's ability to transmit EMF signals, played amongst the V&A's cast collection.
samconran.com

L
Living Among Living Things
The Edwin and Susan Davies Galleries, Room 87
(access via staircase L, follow signs)
Will Carey explores how living things will replace the products and foods we use today: from packaging that produces its own drink to skincare products secreted from bespoke microbial cultures. This series of images show exotic commodities that could be normal to future generations.



M
Neo-Nature
Lunchroom
(access via staircase L, follow signs)
Join this workshop to create your own synthetic corals and contribute to the V&A's very own coral reef. Michail Vanis invites you to bring seemingly impossible scenarios to life and discuss their scientific and ethical implications.
mikevanis.com

N
Synthetic Aesthetics on Film
The Lydia and Manfred Gorvey Lecture Theatre
(access via staircase L, follow signs)
18.30 – 19.00 & 20.00 – 21.45
DNA replication, Bjork, swallowable perfume… these eight films demonstrate a myriad of cultural crossovers; synthetic biology at its aesthetic finest.

Dunne & Raby – *Future Foragers* (2009)
Tobias Revell – *New Mumbai* (2012)
Lucy McRae – *Swallowable Parfum* (2013)
UCSD – *Biopixels* (2011)
Zeitguised – *Comme des Organismes* (2014)
Drew Berry for Bjork – *Hollow* (2011)
Daisy Ginsberg – *E.Chromi* (2009)
Neri Oxman – *Silk Pavilion* (2013)

FROM 19.00

O
***Synthetic Aesthetics* Authors' Panel Discussion and Book Signing**
The Lydia and Manfred Gorvey Lecture Theatre
(access via staircase L, follow signs)
19.00 – 20.00
(followed by book signing)
The authors of *Synthetic Aesthetics* pry open the circuitry of a new biology, exposing the motherboard of nature. A presentation by designer Alexandra Daisy Ginsberg will be followed by a panel discussion with members of the team behind *Synthetic Aesthetics* Drew Endy, Jane Calvert, Pablo Schyfter and Alistair Elfick. Chaired by *The Economist's* Oliver Morton.

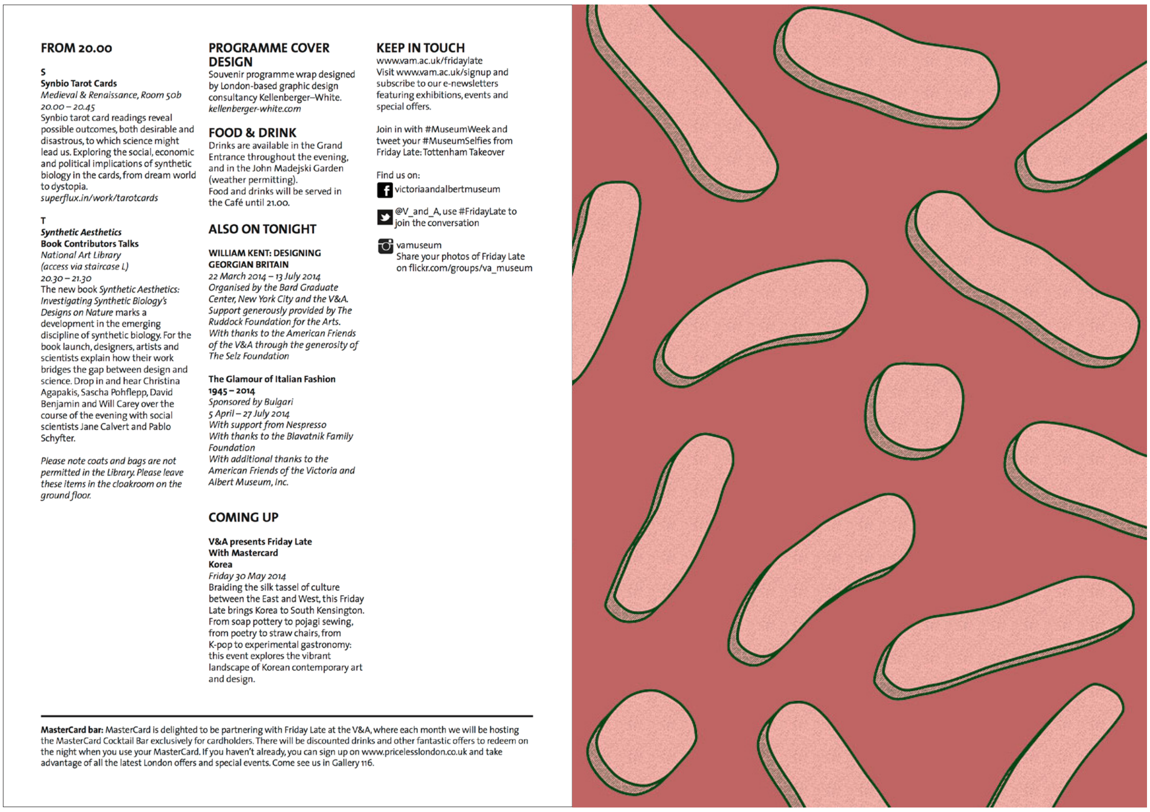
P
Blueprints for the Unknown
Learning Centre: Seminar Room 3
(access via staircase L, follow signs)
19.00. 19.30, 20.00 & 20.30
What happens when science leaves the lab? Recent advances in synthetic biology mean scientists will be the architects of life, creating blueprints for living systems and organisms. *Blueprints for the Unknown* investigates what might happen as engineering biology meets the complex world we live in. Speakers include Koby Barhad, David Benqué, Raphael Kim and Superflux.

Blueprints for the Unknown is a project by Design Interactions Research at the Royal College of Art as part of the Studiolab research project.

Q
DNA Extraction
Learning Centre: Art Studio
(access via staircase L, follow signs)
19.00, 20.00 & 21.00
Extract your own DNA in the V&A's popup Wetlab and chat with synthetic biologists from Imperial College London. Synthetic biology designs life at the scale of DNA, and tonight you can take the raw materials of life home with you. With thanks to Imperial College London's EPSRC National Centre for Synthetic Biology & Innovation and SynbiCITE UK Innovation and Knowledge Centre for Synthetic Biology.

R
Music of the Spheres
John Madejski Garden
19.30 and 20.30 (20 minutes)
Your computer's hard drive is nothing compared to nature's awesome capacity to record information. Artist Charlotte Jarvis explores how DNA can be used to record things apart from genetics – such as music – in the centuries to come. With scientist Nick Goldman and composer Mira Calix, *Music of the Spheres* encodes music into the structure of DNA suspended in soap solution. An immersive, surprising performance introduced by Jarvis, Calix and Goldman as they release musical bubbles in the garden.
artforeating.com/mots

Figure F.1
"V&A Friday Late: *Synthetic Aesthetics*" programme, with cover by Kellenberger-White.



FROM 20.00

S
Synbio Tarot Cards
Medieval & Renaissance, Room 50b
20.00 – 20.45
Synbio tarot card readings reveal possible outcomes, both desirable and disastrous, to which science might lead us. Exploring the social, economic and political implications of synthetic biology in the cards, from dream world to dystopia.
superflux.in/work/tarotcards

T
Synthetic Aesthetics
Book Contributors Talks
National Art Library
(access via staircase L)
20.30 – 21.30
The new book *Synthetic Aesthetics: Investigating Synthetic Biology's Designs on Nature* marks a development in the emerging discipline of synthetic biology. For the book launch, designers, artists and scientists explain how their work bridges the gap between design and science. Drop in and hear Christina Agapakis, Sascha Pohflepp, David Benjamin and Will Carey over the course of the evening with social scientists Jane Calvert and Pablo Schyfter.

Please note coats and bags are not permitted in the Library. Please leave these items in the cloakroom on the ground floor.

PROGRAMME COVER DESIGN
Souvenir programme wrap designed by London-based graphic design consultancy Kellenberger–White.
kellenberger-white.com

FOOD & DRINK
Drinks are available in the Grand Entrance throughout the evening, and in the John Madejski Garden (weather permitting).
Food and drinks will be served in the Café until 21.00.

ALSO ON TONIGHT

WILLIAM KENT: DESIGNING GEORGIAN BRITAIN
22 March 2014 – 13 July 2014
Organised by the Bard Graduate Center, New York City and the V&A.
Support generously provided by The Ruddock Foundation for the Arts.
With thanks to the American Friends of the V&A through the generosity of The Selz Foundation

The Glamour of Italian Fashion 1945 – 2014
Sponsored by Bulgari
5 April – 27 July 2014
With support from Nespresso
With thanks to the Blavatnik Family Foundation
With additional thanks to the American Friends of the Victoria and Albert Museum, Inc.

COMING UP

V&A presents Friday Late With Mastercard
Korea
Friday 30 May 2014
Braiding the silk tassel of culture between the East and West, this Friday Late brings Korea to South Kensington. From soap pottery to pojagi sewing, from poetry to straw chairs, from K-pop to experimental gastronomy: this event explores the vibrant landscape of Korean contemporary art and design.

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Join in with #MuseumWeek and tweet your #MuseumSelfies from Friday Late: Tottenham Takeover

Find us on:
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vamuseum
Share your photos of Friday Late on flickr.com/groups/va_museum

MasterCard bar: MasterCard is delighted to be partnering with Friday Late at the V&A, where each month we will be hosting the MasterCard Cocktail Bar exclusively for cardholders. There will be discounted drinks and other fantastic offers to redeem on the night when you use your MasterCard. If you haven't already, you can sign up on www.pricelesslondon.co.uk and take advantage of all the latest London offers and special events. Come see us in Gallery 116.

Figure F.2
Grand Entrance Live Lab.

Process

Synthetic biology was unfamiliar subject matter for the museum, so, once we had confirmed the event in October 2013, I was asked to provide content suggestions for Ruth Lie, Friday Late coordinator, who would curate the programme. I sent first ideas in December 2013. In early 2014, I learnt that Lie was going on maternity leave in early April; her cover, Jennifer Zielinska, would only join the V&A in April and this would be her first project. With most content still to be planned, I stepped in from early February, working with Lie and the CADD team to curate the content, invite participants, seek additional funding, build relationships, develop the laboratory, and negotiate the political agendas of synthetic biologists and the EPSRC (see Chapter 6). Our small budget from regular sponsors MasterCard meant we had, where possible, to identify local projects to minimise costs. Fortunately, the EPSRC agreed to provide additional funding to permit some Synthetic Aesthetics team and residents to attend and give talks.

Following the success of GYO's gallery laboratory, I asked Paul Freemont at SynbiCITE if they could supply and staff the laboratories, which he agreed to. While this was useful public engagement for SynbiCITE, both institutions were also interested in building this new relationship; the Science Museum is more familiar territory for its Imperial College neighbours. Bringing any living biological matter into the museum also presented new questions for the V&A's conservators (see Chapter 6). With our budget stretched, we decided against using genetically modified organisms (GMOs) at the V&A (unlike at GYO), because of the cost of a licence used for a single event. I worked with SynbiCITE and Professor John Ward of University College London to select experiments and organisms for the labs that avoided genetic modification. The Grand Entrance Live Lab was sealed to prevent members of the public from entering, but they could talk with the synthetic biologists inside (figure F.2-4). We located a pop-up wet lab in a classroom; there, SynbiCITE's scientists showed visitors how to extract DNA from strawberries (figure F.5). This basic protocol provides a tangible outcome for participants, as the DNA visibly clumps together. I felt it was important to communicate DNA's materiality as part of the discussion around designing biology, especially since I expected many of our audience to have different interests from those associated with choosing to attend a Science Museum event on the same subject.[2]

Typically for the Friday Late format, we asked participating artists, designers, scientists, and engineers to attend, if possible, to explain their work to the public. Some projects were adapted from GYO: Jannis Hülsen and Stefan Schwabe talked with visitors about their *Xylinium Cones* (2013), their objects grown from bacterial cellulose (figure F.6); meanwhile, biohackspace La Paillasse's "Grow Your Ink" workshop was presented as a demonstration (figure F.7). In the richly tiled Victorian café, Christina Agapakis presented an iteration of *Selfmade* (2013-), her Synthetic Aesthetics work with smell provocateur Sissel Tolaas that used swabs from feet, noses and armpits as starter cultures for "human cheeses". Agapakis made new human microbiome cheeses, and also sampled the V&A's iconic Silver Lions (1885) to produce a portrait of the museum's microbiome (figure F.8).

2 Also, many attend the Friday Late to visit the museum, regardless of theme.

Figure F.3-4
Experiments and live bacterial cultures in the Grand Entrance Live Lab.

Figure F.5
“DNA Extraction” workshop run by SynbiCITE synthetic biologists.

Figure F.6
Xylinium Cones (2013) by
Jannis Hülsen and Stefan
Schwabe in the museum’s
Lunch Room.

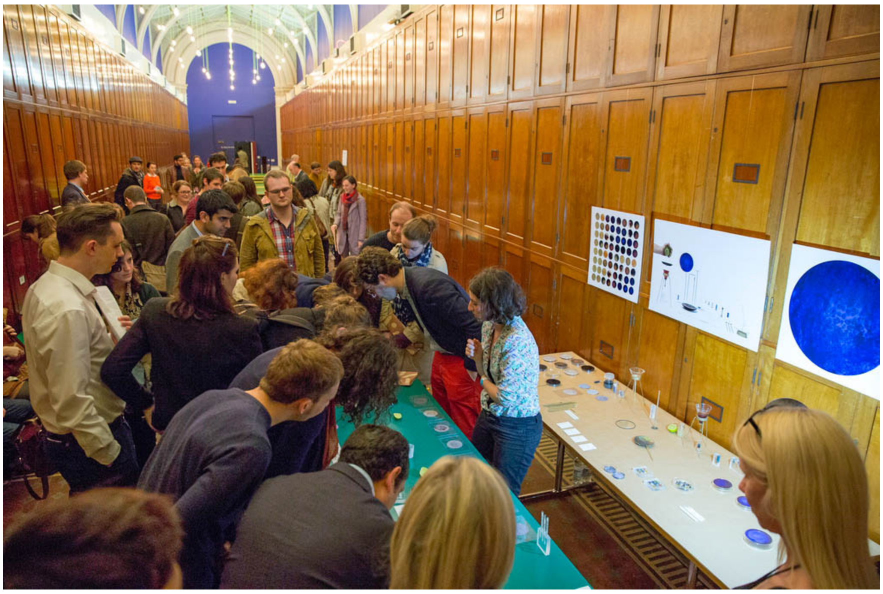

Figure F.7
Synthetic biologist Thomas
Landrain and designer Marie-
Sarah Adenis of La Paillasse
demonstrate how to “Grow
Your Ink” (2014).

Figure F.8
“Human cheese” in the café: *Selfmade* (2013) by Sissel Tolaas and Christina Agapakis.

Figure F.9
Resurrected vocal cords of the extinct hominid *Australopithecus afarensis*, known as Lucy, from Marguerite Humeau’s *The Opera of Prehistoric Creatures* (2011-), singing in the Raphael Gallery.

Figure F.10
Living Among Living Things (2011) by Synthetic Aesthetics residents Will Carey and Adam Reineck in The Edwin and Susan Davies Galleries.

Figure F.11
Natsai Audrey Chieza's *Faber Futures* (2012-) experiments in the Tapestry Gallery.

Despite the small budget, we commissioned some new work. Filled with monumental nineteenth-century plaster replicas, the Cast Court reverberated with Sam Conran's site-specific commission, *Electromagnetic Signals from Bacterial DNA*. His musical composition speculated on the sounds of bacterial communication, making visitors feel like microscopic organisms as they wandered amongst the towering casts. In the museum's courtyard, artist Charlotte Jarvis and scientist Nick Goldman presented their work in progress, *Music of the Spheres*, releasing soap bubbles containing DNA encoded with music.

Elsewhere, Autodesk introduced their shape- and pattern-shifting smart textiles, an offshoot of their work in software for biological design. In the lecture theatre, we screened short films ranging from scientific projects like the engineered, blinking *Biopixels* by researchers at the University of California at San Diego to Drew Berry's visualisation of magnified tissues and cells for musician Björk's track *Hollow*. In the Medieval and Renaissance Rooms, design practice Superflux ran a "Synbio Tarot Cards" session, inviting members of the public to conjure up future scenarios. The location of *The Opera of Prehistoric Creatures*, by Marguerite Humeau (see Chapter 6), in the Raphael Gallery (figure F.9), was hard won, justified in an essay to the gallery's curator by one of the CADD team. Juxtaposing these works with the museum's treasures allowed reflection on past and future values.

In the publicity material, we described synthetic biologists' manipulation of the stuff of life as "crossing the boundary between science and design", casting them as "designers" who "see life as a programmable material, creating new organisms with radical applications from materials to machines". This let us question what *good design* of living matter means. Placing objects made by humans against those made by biology suggested new meaning for "design", stimulating questions around *why* humans design biology (figure F.10-11).

The process was not without trouble. As Chapter 6 described, Drew Endy asked to cancel the event just two weeks beforehand. I had kept the Synthetic Aesthetics team informed throughout the curatorial process, and Endy had a sense of the content, having visited GYO in January 2014. Certainly, we had a tiny budget compared to an event like iGEM or the SBx.0 conference series. But changing synthetic biology's framing did not mean eliminating science: respecting the participating synthetic biologists' agendas and autonomy rooted the event in reality and emphasised the importance of discourse. Working with SynbiCITE on the Live Lab, I remained conscious of their engagement needs, as well as managing the EPSRC's desire to publicise the project, for example their wish to invite the then science minister, David Willetts. As discussed in Chapter 6, Willetts ultimately attended in a personal capacity, informally introducing the authors' panel, pleasing the funders and synthetic biologists. On the morning of the event, Endy was interviewed on BBC Radio 4's flagship *Today* news programme, promoting both synthetic biology and the event. Operating from the V&A allowed synthetic biology to be framed as a societal matter, not just one of innovation.

Appendix G: “Grow Your Own… Life After Nature”

This appendix provides more detailed documentation of the “Grow Your Own” exhibition to support its evaluation in Chapter 6.

Description

The exhibition “Grow Your Own... Life After Nature” (GYO) at Science Gallery, Trinity College Dublin (SGD), ran from 25 October 2013 to 19 January 2014. Bringing together engineers, scientists, designers, artists and biohackers, the show used art and design to explore the “potentially ground-breaking applications and uncertain implications of synthetic life” (Science Gallery 2013). I was lead curator for GYO, with co-curators Paul Freemont, Anthony Dunne, Cathal Garvey (biohacker), and Michael John Gorman (SGD’s director). The exhibition received 45,167 visitors over its three-month run.

From April 2013, I led GYO’s curatorial development, and the open and invited calls for exhibits. I worked with the SGD team to commission new work, produce the exhibition catalogue (Ginsberg et al. 2013) and microsite (Science Gallery 2013), develop the design of communications and the exhibition space, and create the events and residencies programme. This overlapped with starting the PhD at the end of September 2013. I visited the exhibition multiple times during its run, observing visitors in the space, participating in events, and interacting with the residents. Several projects developed for GYO were included in the “V&A Friday Late: *Synthetic Aesthetics*”, where we also developed the gallery laboratory concept.

This was the first time I had curated an exhibition; working with a diverse, expert curatorial and production team developed my critical practice. Research into the existing practice linking art, design, and synthetic biology provided a foundation for the PhD, deepening my expertise and revealing new spaces to explore. Balancing the curatorial team’s and the institution’s varying agendas and interests was useful for identifying boundaries between didacticism, hyping imaginaries, and the exploration and critique of them.

Background

Opened in 2008, Science Gallery’s (2017) mission is to provide a space to discuss science and its future directions with content targeted at young adults aged 15-25. It has no permanent collection or entry fee. SGD is funded by the Wellcome Trust, the SGD Science Circle (including corporate sponsors such as Deloitte, Google, and Pfizer), the Irish government and the European Seventh Framework Programme. Located on the Trinity College Dublin campus, the building also houses laboratories, offices, meeting rooms and a café: 72,000 people visited the building during GYO's run. Science Gallery is expanding internationally, with a London venue opening in 2018, and plans for Melbourne, Bangalore, Venice and Detroit underway.[1]

SGD's curatorial teams usually consist of invited specialists consulting on a show's cross-disciplinary theme, e.g. "Surface Tension: The Future of Water" (2011-12), or "Illusion: Nothing Is As It Seems" (2013). Generally, a curatorial research assistant works full time on site during the show's development, producing the exhibition with SGD's team. Open calls for submissions contribute to exhibition content. A team of "mediators" are always in the gallery space, trained to explain the works.

In early 2013, SGD asked me to join GYO's curatorial team. I began research in April, working from London. GYO was unusual for SGD since it was structured around a particular field, not a broad topic. As I was expert on art and design's interactions with synthetic biology, I came to lead the curatorial team. Anthony Dunne had previously curated "What If...?" (2009) with Fiona Raby at SGD (in which I had shown work), which also fell outside the standard rubric.

GYO was funded by the Wellcome Trust, and was part of the three-year Studiolab project, a European Seventh Framework Programme funded in 2011. The Royal College of Art's Design Interactions department was also one of Studiolab's eleven partners. We liaised with another partner, Ars Electronica, in Linz, whose concurrent exhibition on synthetic biology, "Yours Synthetically", opened in August 2013.

Aims

The curatorial team wanted the exhibition to explore synthetic biology and its potential implications, without being didactic or promotional. We prioritised openness and the creation of a space for discussion about what society should or shouldn't pursue with this technology. We sought to include both living biological matter and speculative works to link the current reality with possible futures, whilst clearly labelling the real from the fiction. We wanted to equip visitors to discuss the questions around designing life, without being limited to either the current science or its promises. I wanted to develop my critical design practice and find new ways to frame these questions. Working from a cultural space for the first time, rather than from synthetic biology (as I had in the Synthetic Aesthetics project) would inform this process.

1 I am part of Science Gallery London's "Leonardo" expert group, contributing to programming ideas.

Credits and Acknowledgements

- Curated by Alexandra Daisy Ginsberg, Paul Freemont, Anthony Dunne, Cathal Garvey, and Michael John Gorman;
- Ian Brunswick, Conor Courtney, Fionn Kidney, Ruza Leko, Ailve McCormack, Roisin McGann, Shaun O'Boyle, Rob Warren, Lucy Whitaker, and the SGD team;
- Community BioLab residents, exhibiting artists and designers, and visiting speakers (see below);
- Funded by the Wellcome Trust.

Process

Following SGD's rubric, we launched an open call for projects in late April 2013 (Studiolab 2013), which I wrote, as well as developing an invited call to commission a few new works. At the end of May, the SGD team and I drew up a shortlist of entries from both calls to present at the curatorial meeting in early June, where we selected projects and new commissions. We funded two new works, including my *Designing for the Sixth Extinction* (a decision I recused myself from), and five iterations of existing projects. Further works submitted in the calls were commissioned for the Community BioLab programme or were developed as events.

Our choices, plus the addition of other projects, were based on my research mapping of existing work and the issues it addressed, as well as development of the show's organising themes since April. I regularly reviewed this material with the curatorial team. Content was finalised over June and July, and I continued advisory discussions with the commissioned artists and designers. I contributed to catalogue development, exhibition and communication design, and the residency and events programme until the show's opening in October. SGD has internal designers, but brought in consultants to develop the communication design, aimed at SGD's target audience of 15-25 year olds. What engagement with this group meant was a constant point of discussion.

The exhibition itself was divided into three rooms, reflecting SGD's architecture (figure G.1). The downstairs gallery is visible from the street and has pedestrian traffic passing directly through to the shop and café. We chose to keep the natural light to set the show's open atmosphere. This room, "Grow Your Own... Life", dealt with the premise of life as designable matter and the blurring of boundaries between design, and us (figures G.2-4). The first thing visitors encountered on entering this room was the Community BioLab, designed to appear permeable and welcoming through glazing and plywood fins. Upstairs, the second room, "Grow Your Own... Society" (figure G.5-7) addressed interactions between designed biology and existing societal and ecological systems. The final internal room was kept darker, and themed, "Grow Your Own... Machine" (figure G.8-9), where we examined synthetic biologists' use of the metaphor of biology as machine. For a visual summary of projects, see figure 5.2.

Room One: “Grow Your Own… Life”
Community BioLab*;
Banana Bacteria (2011) by Howard Boland;
All That I Am (2011) by Koby Barhad;
E. chromi: The Scatalog (2009) by Alexandra Daisy Ginsberg and James King;
New Mumbai (2012) by Tobias Revell;
Selfmade (2013) by Christina Agapakis and Sissel Tolaas**;
I Wanna Deliver A Dolphin (2011) by Ai Hasegawa;
Post Natural History (2012) by Vincent Fournier;

Room Three: “Grow Your Own… Society”
Blighted by Kenning (2011) by Charlotte Jarvis;
The New Weathermen (2013) by David Benqué;
Stranger Visions (2013) by Heather Dewey-Hagborg**;
Teen Gene Poems (2009–2013) by (Art)ScienceBLR (ArtScienceBangalore)**;
Common Flowers/Flower Commons (2008) by BCL (Shiho Fukuhara and Georg Tremmel)
Into Your Hands Are They Delivered (2013) by Tobias Revell;
Designing for the Sixth Extinction (2013) by Alexandra Daisy Ginsberg*;

Room Three: “Grow Your Own… Machines”
Xylinium Cones (2013) by Stefan Schwabe and Jannis Hülsen **;
The Mechanism of Life—After Stéphane Leduc (2013) by Oron Catts, Ionat Zurr and Corrie van Sice;
The Great Work of the Metal Lover (2012) by Adam Brown in collaboration with Dr. Kazem Kashefi;
Zero Park (2013) by Sascha Pohflepp*;
Faber Futures: The Rhizosphere Pigment Lab (2013) by Natsai Audrey Chieza with Professor John Ward**;
Circumventive Organs (2013) by Agatha Haines.

* New commission.
** Development of existing project.

Artworks appearing in GYO.

I visited the exhibition in October and November 2013, and in January 2014, participating in events and observing how audiences were interacting with the content, the mediators and Community BioLab residents (figure G.10-11). The public seemed interested, with positive reviews in the scientific press (e.g. A. King 2013), as well as coverage in mainstream media (e.g. Reilly 2013).

Figure G.1
Street view of SGD, with the Community BioLab in Room One (ground floor) on the left.

Figure G.2
Room One: "Grow Your Own… Life" showing Koby Barhad 's *All That I Am* (2011) juxtaposed with the Community BioLab.

Figure G.3
Selfmade (2013) by Christina Agapakis and Sissel Tolaas in Room One. This was the first time their Synthetic Aesthetics project had been exhibited; visitors were invited to open the fridges and smell each microbial portrait. Donors included Hans Ulrich Obrist, Michael Pollen, Olafur Eliasson, and cheese scientist Ben Wolfe.

Figure G.4
View of Room One looking back towards the Community BioLab, with a Science Gallery mediator discussing Ai Hasegawa's *I Wanna Deliver A Dolphin* (2011) with visitors.

Figure G.5
View of Room Two: "Grow Your Own… Society", with David Benqué's *The New Weathermen* (2013) on the far right, at the back right is the entrance to Room Three.

Figure G.6
Room Two showing Charlotte Jarvis' *Blighted by Kenning* (2011), with my *Designing for the Sixth Extinction* visible behind.

Figure G.7
Room Two: growing copies of hacked GM carnations in *Common Flowers/Flower Commons* (2008) by BCL.

Figure G.8
Room Three: “Grow Your Own… Machines” with Sascha Pohflepp’s film installation *Zero Park* (2013) at the front, and *Xylinium Cones* (2013) by Stefan Schwabe and Jannis Hülsen visible at the back left.

Figure G.9
Installation view of *Xylinium Cones* (2013) by Stefan Schwabe and Jannis Hülsen.

Figure G.10
Parisian biohackspace
La Paillasse developed a
workshop called “Grow
Your Ink” (2013) for
their Community BioLab
residency.

Figure G.11
Workshop with Genspace’s
Ellen Jorgensen: the
Community BioLab provided
a space for visitors to directly
interact with biological material.

COMMUNITY BIOLAB RESIDENCIES

Week 1: Ellen Jorgensen, Genspace community laboratory, New York City

"Biohacking - A brief introduction, with Ellen Jorgensen", 6—7pm, 31 October 2013;

Drop-in workshops all week with Ellen Jorgensen from Genspace, 12—6pm, 1 November 2013;

Biohacking workshop with Genspace, 2—5pm, 2 November 2013.

Week 2: Yashas Shetty (ART)ScienceBLR, Srishti Institute of Art, Design and Technology and Mukund Thattai, National Centre for Biological Sciences, Bangalore

"What's in that Tube?" Workshop with (Art)ScienceBLR, 3—4pm, 7 November 2013;

"Ancient Life, Artificial Life" talk by Yashas Shetty and Mukund Thattai, 5.30—6.30pm, 8 November 2013;

Drop-in workshops all week with (Art)ScienceBLR, 12–6pm;

"Pearse Street Customs" with (Art)ScienceBLR, 2—5pm, 9 November 2013.

Week 3: Christina Agapakis, UCLA, and Sissel Tolaas, Berlin

"A Short Introduction to Cheese (and "Human Cheese')", 6—7.15pm, 13 November 2013;

"'Human Cheese' and Wine" reception and talk with Seamus Sheridan of Sheridan's Cheesemongers, 6—7pm, 15 November 2013;

Drop-in "Human Cheese" workshops all week with Christina Agapakis and Sissel Tolaas, 2—4pm;

Cheese-making workshop with Christina Agapakis, 2—4pm, 16 November 2013.

Week 4: Science Gallery

"Grow Your Own… Home-made Microbiology", 3—4pm, 20 November 2013;

Drop-in workshops all week with Science Gallery, 12–6pm;

"Build Your Own DIY Lab", 2–4pm, 24 November 2013;

Family Members Event: "Microbes and Microscopes", 12.30—1.30pm, 24 November 2013;

Week 5: Jemma Pilcher and Margarita Kopniczky, SynbiCITE, Imperial College London

Drop-in workshops all week on "Bioplastics, Living Art and iGEM", 12—6pm;

"Living Art Workshop: The 1 Hour Intro", 3—4pm, 29 November 2013;

"Living Art Workshop: The 2 Hour Edition", 2–4pm, 30 November 2013.

Week 6: Cathal Garvey, biohacker, Cork

Drop-in DIYbio Workshops all week with Cathal Garvey, 12:00-18:00, 2—6 December 2013;

"Grow Your Own… Kombucha Pancake", 3—4pm, 4 December 2013;

Drop-in "Seasonal Synthetic Biology Workshops" all week, 12—6pm;

"Private Ownership and the Commons of Life", talk by Cathal Garvey, 6—7pm, 6 December 2013;

"Culture Your Own Probiotics" with Cathal Garvey, 2–4pm, 7 December 2013.

Weeks 8—11: Science Gallery

Week 12: Thomas Landrain and Sarah Adenis, La Paillasse, Paris

"Grow Your Own… Ink" with La Paillasse, 3—4.30pm, 16 January 2014;

"Grow Your Own… Ink" with La Paillasse, 3—4.30pm, 17 January 2014;

Drop-in workshops on "DIY Bio and Synthetic Biology" with Thomas Landrain of La Paillasse, 12—6pm, 14—19 January 2014.

GYO Events Programme.

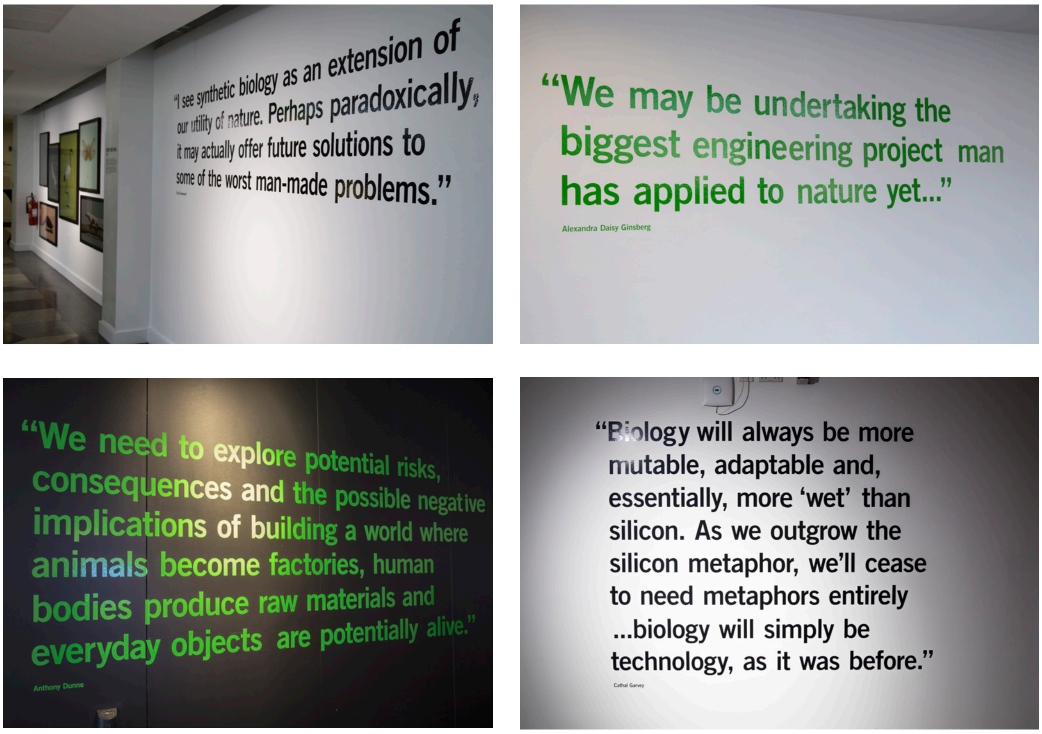

Figure G.12-15
Wall texts showing the curators' different views on the subject.

To show that this technology, and its role in our future, is not fixed, we chose to use an unfinished plywood in the exhibition design, which the SGD team and fabricators developed into a partition and plinth system. Alongside the text explaining each room's theme, large-format quotes from four of the curators (figure G.12–15) on the walls of Rooms One and Three communicated uncertainty around the field and its promises, even revealing conflicting views within the curatorial team. This lack of consensus carried through into the catalogue, where we asked the curators to answer a series of questions relevant to their practice, each interview starting with: "What is synthetic biology to you?". We also asked participating artists, designers and scientists to contribute to the discussion, reflecting on either: "How might synthetic biology change the way we live?" (Ginsberg et al. 2013, pp.34-38), or "What new or unexpected challenges might designing biology present?" (2013, pp.54-58). Showing a range of views, from excitement to concern to apathy, encouraged visitors to see this technoscience and its future as far from fixed; their own questions and insights were valid.

MAIN TALKS AND EVENTS

"Grow Your Own… Launch Party", 6pm–8pm, 24 October 2013;

SFI Speaker Series: "Grow Your Own… Curators Talk", 6–7.15pm, 25 October 2013;

"Adam Rutherford on Creation, Synthetic Biology and Hip-Hop", 6–7.15pm, 7 November 2013;

"The Science Gallery Book Club: *Creation*" by Adam Rutherford, 6.30–7.30pm, 1 November 2013;

"Grow Your Own… Supper Club" with Cat Kramer and Zack Denfeld, 7–9pm, 8 November 2013;

"Media Hype and Synthetic Biology" with Alok Jha and Christina Agapakis, 6–7pm, 13 November 2013;

"The Synthetic Biology Smackdown" hosted by Alok Jha (SFI Speaker Series), 6–7.15pm, 14 November 2013;

President of Ireland Ethics Initiative: "Designing Life: The Ethics of Synthetic Biology" with Professor Drew Endy (Stanford University) and Hugh Whittall (Director of the Nuffield Council on Bioethics), 6–7.15pm, 16 January 2014;

"Synthetic Biology Superheroes: Comic Book Design Workshop" with Johanna Schmeer, 2–5pm, 23 November 2013.

Appendix H: Interview with Drew Endy

Conducted over Skype on 20 January 2016 between the author in London, UK, and Drew Endy in Menlo Park, CA, USA.

ADG: I want to talk to you about the idea of the better future in synthetic biology and where it is going now, and the ideas that we have been developing about where it could go. In your experience, what do you think that the better future could mean in synthetic biology? What are the values or definitions of a better future that synthetic biology could aspire to?

DE: For me, I think it is central to realising a transition from living on earth, to living with earth. And I mean that comprehensively. So over my lifetime the human population has doubled, from three and a half to seven plus billion; the wild animal populations have dropped by a factor of two; and you know, it just doesn't seem awesome. It also seems that there are these trends of centralisation of technology, centralisation of manufacturing, building upon industrialisation, if you will, and so people have become consumers more than citizens, perhaps increasingly. So going forward, you take a couple of different pieces of a puzzle: how are we going to make all the stuff that we need; how are we going to make all the stuff that everybody needs; and who is going to be in control of that, and who is going to define what gets made, and decide how to make it, and will individuals still have agency if we can get to that future? When we get to that future, what will it mean to be a citizen?

I think that synthetic biology is in the middle of all of this, so you see synthetic biology get applied to make biology that goes to market. Typically within an industrial frame: industrial fermentations for centralised manufacturing of medicines. The artemisinin project, which is not a synthetic biology project *per se*, but an example of what can be synthesised with biology, ends up with a yeast strain that runs in a fermenter in Italy. And that displaces the distributed manufacturing of artemisinin via the farming of the wormwood plant, by many people all over the place. So, is that *better*? Well, from some perspectives it is. Stable supply, stable reliability of incorporation into trivalent therapies that resist emergence of resistance in the population, but from many other perspectives it's not better: it displaces workers, it removes agency, it shifts land use burdens, probably in good ways, but not fully understood.

So, maybe you can ask your question again and I can help myself think about it anew. But for me, synthetic biology is in the middle of a transition from enabling us to live on earth, to enabling us to live with earth, where we don't change human nature, but we change humanity's relationship with nature. So that we are better integrated with resources and recovery of materials and energy. I'll admit, by the way, that there is another camp in synthetic biology, or beyond synthetic biology, which is actually not interested in changing humanity's relationship with nature, but is interested in changing humanity. And maybe views synthetic biology as a means to eventually digitising the brain and going into the cloud, so to speak. And they end up caring more about energy and bits as opposed to energy, bits and atoms. But we can't really pull that off right now, because we don't understand how we work, so we're going to need some biological technologies so that we can do the uploading.

ADG: Do you think that is a good version of a better future? Changing humanity for better, is that part of your understanding of what better could be? Are you in that camp?

DE: Only in a very limited sense. I feel like I might be one of those people who is stuck with my meat wagon, my corporeal being. I don't go so far as to remain satisfied with statements like "suffering defines the human condition", but I do think that some attachment to our corporeal being and its finite capacities is good.

ADG: Yes, I think it helps us.

DE: But just to admit, not everybody feels that way. There is not….

ADG: …but with questions like this artemisinin issue… I was at a workshop about Responsible Research and

Innovation last week, with the UK social scientists and now historians and philosophers—it's expanding—and Oron Catts came along too. We caused some mayhem! I'm interested in RRI because it doesn't *mean* anything: because, again, there are multiple betters, and multiple kinds of innovation. It seems to capture one kind of innovation, which is market-led innovation, rather than expanding what innovation could be: innovating people's happiness or innovating welfare, or innovating our relationship to nature. I think that the artemisinin question is one that captures a lot of these debates about how there are multiple viewpoints that we can't resolve. Do you think that with artemisinin, the values that drive that particular discussion, do you think that there is any way to evaluate, from your perspective within the science, what is better in that sense?

DE: Well the variables that I'd look at would be: efficacy of the thing being made, reliability and cost of the process to make it, fairness in terms of how it deploys, net impact on land use and then changes in agency and employment. It's not that every dimension or aspect has to be positive. You can mitigate things that are negatives.

You know, I think that one of the big gaps right now is the multi-dimensionality of projects is typically not considered. And this is normal, and sometimes healthy, because when you're doing something that is totally new from one perspective, it's innovative technology that has not been realised before. If you try and sort everything else out at the same time, you simply won't do anything, because doing anything for the first time is really hard. To the extent that synthetic biology is caught up in this goal of making it easier to do stuff, as we have these experiences of doing things for the first time, we are also making it easier to do things for the first time, we have to mature and upgrade our capacity to think about, consider, assess and take action as needed, along the dimensions of better. Promoting the positives and mitigating the minuses.

ADG: There's something that I thought that was really interesting in Jennifer Doudna's opinion piece she wrote [(Doudna 2015b)] at the end of the year about her "Whirlwind Year with CRISPR"; she finished off saying that as scientists, "We need to be better equipped to ask these kinds of questions and to evaluate the sciences", but then it led into a discussion of how "We need to be better at elevator pitches and better at media training". But it seems to me to be a genuine opportunity there to say "What are the tools that we need to develop to work with science?", to start to take into account that these are really complex issues, and that there aren't right answers.

DE: In part, but a particular type of tool that I think is often overlooked is getting the scientist… avoiding the mistake of having the scientist have responsibility for figuring it out. So if we use Jennifer as an example, you know, what is her role in deciding whether or not CRISPR-enabled gene drives for avian malaria should be deployed in Hawaii, to protect the native bird species from extinction?

ADG: It's not her expertise, as far as I know.

DE: Well, I don't know. Maybe she's from Hawaii [she is]? Does that give her a voice, does that give her more of a voice than being one of the innovators of CRISPR? You know, but I think there is a sort of a default frame, which is the researcher has responsibility for everything, and that can't be healthy.

ADG: Yes. I found that article really useful as a way of seeing opportunity for, you know, spaces where design or art or social science, or anthropology or economics or all these different things could come together to create different kinds of tools to examine with the science in a more collaborative way. This is where the RRI thing really shows up how it is just being used here—I don't know if you have the same in the US? It's just seems empty.

DE: Can I ask you a question about that? So you sort of map that onto a type of economic metric. But does that metric then allow for the existence of *irresponsible* research? So, would irresponsible research be research that does not have an economic return?

ADG: Well, yes, I think that's a really nice way of putting it. What I want to do is to say is, "Well, what is responsibility and what is innovation?" I think that at the moment — that is my reading of it — that it is economics-led. From the way the people who are working with Imperial were talking about it, it is very much "How do we help commercialisation?" This is not the only way to think about innovation. If you are going to figure out the bird population in Hawaii, that is not necessarily an economic decision. Saving birds is nice…

DE: It might be if you are on the tourism board.

ADG: Well, how many tourists? The bird-watchers will be the only group who are really affected, in terms of economics! Then of course there will be crops and lots of other things that are indirect, and harder to measure, so it may well be an economic argument. I am all for irresponsibility in terms of finding the weirdness, or different ways of thinking, it can only be a good way of thinking.

DE: I guess I'm offering as a reflection: can you pretend to have defined responsible research if you cannot practically define irresponsible research as well? And I think a weakness of the definition that you are relating is that the irresponsible version, I don't think that anyone would accept that as being valid. Five years ago, CRISPR is basic research. Right? Just a money-loser.

ADG: So what would your definition of irresponsible research be?

DE: That destroys improbability. Anything that decreases improbability.

ADG: OK. But why is that *irresponsible*?

DE: I don't know that it is irresponsible so much, as it is wrong. So, irresponsible would be when you have not struggled to work through… [disrupted line]… when what you are doing is likely to contribute to, or diminish life.

ADG: So we need more irresponsible research, would you say?

DE: I think we probably need more frivolous research.

ADG: That's probably a safer definition!

DE: From *Homo ludens*… [disrupted line]… establishing a culture as a necessary precondition to a culture of utility. So, I think we need more playful work and frivolous work. Especially in biotech, which is almost always over-driven by the immediacy of the application, which is almost always curing disease, or feed the planet, or save the environment.

ADG: Do you think it is driven by that because of the need to justify it when there is so much concern around it as a technology, or is that just a particularly European way of thinking about it?

DE: I think that is completely true. You know, that confronted with concern, a response is to promise benefit. And that goes back to the beginning of genetic engineering, right. The three promises are: we're going to make medicine… [disrupted line]... and analyse gene sequences for dealing with genetic issues, and only one of those has come true, but that was enough to allow for a type of cultural and political and operational cover so that a pragmatic framework could be implemented and things could proceed.

ADG: I think that there seems to be a trend of biotech, that I see as quite interesting, of biotech embracing frivolity. So like Ginkgo working with Christina [Agapakis] and making things smell or extinct flowers or Modern Meadow working with Suzanne Lee, hiring creative people as ways to make it more appealing. Or even, Sputniko at the MIT Media Lab working with Gucci to make a dress that is bioluminescent… I think that is extraordinary as a development.

DE: I admire those corporate acquisitions as you describe, but I wouldn't label them as frivolous. I would label them as shrewd, responsible research investments. So, for example, I bet you are using a computer that was designed in California and made in China. Is that perhaps true?

ADG: It is, I admit, yes.

DE: Yes, so me too. Right? Then we could ask for this corporation, which I believe still to be the largest publicly traded corporation in the United States. Is Apple a technology company? Or a design company? I think the answer is that it is some combination of both. I think that there is massive value to be realised through design. And when you bring that to biotechnology, you know, I think it is pretty easy to get many people to say: we haven't imagined most of the things that can be done with biotechnology. So, engaging professionals who are actually good at imagining what people might wish for, whether we know it or not, just seems really shrewd from a business perspective, from a making money perspective.

ADG: So that was the next question. Making money. I wanted to go to our old conversation about disruption and my original quote, which was that synthetic biology promises to be disruptive, but it also promises to do that whilst disrupting nothing, which goes back to keeping the status quo. What are the tools that we need to counter the industrialisation? If synbio could be made better, what would you hope for? What is the disruption you would like to see, and how would we get there?

DE: I think it has to do with understanding, some combination of understanding, reversing or enabling transitions from a culture of compliance, a culture of consumption. Understanding those, replacing those, or transitioning away from those, with or towards a culture of citizenship. So you know there really are unique things about biology. It supports manufacturing wherever the biology is. You don't have to do it necessarily in a centralised factory. It's also unique in that we are all of biology, we all have a stake in it; we're of it, quite literally. So you know to the extent that synthetic biology has to do with making it easier to translate human intentions, and instantiating those intentions into operational living matter, there is a question of agency, there's a question of access, there's a question of control, or the absence of control.

So, you know, for me, if I live in the future and work backwards, I would predict that from a regulatory perspective, the policies that would be most effective in terms of regulating biotechnology, enabled by synthetic biology, would be found in the US Supreme Court cases having to do with regulation of poetry, or regulation of speech. So this is the two Supreme Court cases coming out of Ohio in the 1960s. One is Jacobellis v. Ohio, and the other is Brandenburg v. Ohio. And these effectively define how we regulate poetry in the U.S. So you can say whatever you want if you are a poet, unless it is obscene. And that is not defined explicitly, rather you know it when you see it, it's the very famous decision. And then the other ruling, the Brandenburg case, has to do with the use of speech to incite lawlessness. So are you intending to incite lawlessness? And are you likely to succeed in inciting lawlessness? And if the answer to both of those questions is "yes", then your poem is not protected speech. Is your poem going to actually succeed in inciting lawlessness, is that what you intend? So it is interesting that in a policy framework, these two decisions are promoting a culture of citizenship. Everything goes except for a few of these outlier cases, which we need to be mindful of because they will destroy the body public. Otherwise anything goes.

As opposed to, you know, what you see in terms of compliance, approved manufacturing processes, biosafety regulations, biosecurity regulations, selected agent lists [?]. You know, like, "OK, unless it's this or that or the other things, or 30% like this thing." You know the problem with the compliance culture is that it doesn't scale. And as synthetic biology actually succeeds and it will be easier to do stuff, more people will do more things more quickly. And so you can't expect that your compliance culture is going to work. You might have gotten me off track. I might have gotten myself off-track. Apologies.

ADG: No, no! Because it is about different models. One of the questions that I have is: how if we think about synthetic biology as a design discipline, if you are designing something that is going to change, or take the best qualities of design, how do you patent it?

DE: Take as a specific recent example; take the response to my wife's work [Christina Smolke], right? So full biosynthesis of opiates in yeast from sugar. And what the tabloid out of London—and I think it is called *Nature*— did, it covered that. So initially, they run some articles on home-brew heroin. Which calls for massive regulation, and I think also, you know, calls the work irresponsible. All right, so that's an example of what the policy committee, embedded within synthetic biology, is proposing and promoting. But does that lead to a better world? Can you actually implement that? It is parroting and carrying forward the policy frame of criminalisation, restriction, compliance. And many would say that hasn't actually gotten us to a better place. As a result in part, there are more casualities in the United States from opiate abuse than car deaths now, so 30,000-plus annually. It is absolutely terrifying. So how would you govern yeast-based opiate biosynthesis if it led to everybody on their doorstep every morning practically having a free bottle of hydrocodone, or pick your favourite painkiller? How would you govern that? Would your policy framework be to send somebody round every morning before people wake up and collect all the bottles and burn them? That would be one approach. Or maybe instead you would explore something like what has been happening in Portugal around decriminalisation of possession, investments in de-stigmatisation of addiction, education of public health professionals, resources to treat addiction. I'm not saying that is a perfect answer, either, but it is an example of how a culture of citizenship might be better than a culture of compliance. And I think that synthetic biology is going to be right in the middle of this over and over and over again, where so many of our reactive frames have the conceit that we can control things, that we can limit things, and in part this derives from top-down centralisation and industrialisation. But when you talk about doing that in the context of biology, there really aren't that many examples of that working. Because of the innate distributed nature of biology, of life. And if you start to deploy frameworks and regimes that actually enable that, this could be massively abused.

ADG: Well, as they already are, which is one of the reasons there is public reticence around GMOs, because they feel that it is a top-down controlled system that there is something wrong about how that interfaces with biology. There is a sense that it doesn't quite fit.

DE: And from a consumer perspective, it's just a shitty product that nobody wants. Farmers might want it, but eaters don't want it.

ADG: Well it's killing everyone… sugar is what is killing us.

DE: Well, I just want my food to be pure, Daisy! Well, it's interesting the papaya case, out of Hawaii. So before there was big, bad Monsanto dominating the conversation, there was a virus that started taking out the papaya farming in Hawaii. And a professor at the University of Hawaii worked with the famers, got a little bit of money from the government, and made a strain of papaya that, if I remember the details correctly, expressed a little bit of the virus capsid protein in the plant, thereby confirming a type of immunity to the plant and protecting it from the actual infection. And that was given away for free. And as a result, it saved the papaya farming in the islands. And you know, pretty much everyone had been OK with that. Until, it sort of circled back, and people became aware that there was a massively deployed GM product in Hawaii. Papaya. And when the immune response triggered by industrial GM got back to Hawaii, it wasn't capable of discriminating between how a technology had been developed, who controlled it. It was just bad; intrinsically bad. But it is a fine example of how a type of strangeness can emerge where people don't want something to happen: it ends up triggering a conversation about safety and responsibility. Those conversations lead to guidelines or policy or law that force a type of compliance. Those requirements have significant costs, in turn that creates barriers to practice, which in turn favours industrial actors that are centralised and have capital. There are some vicious feedback loops that are interesting in terms of reinforcing consumption over citizenship.

ADG: What I mean by it killing us is that fructose or corn syrup is the biggest health risk, far bigger than what kind of corn syrup it is [i.e. GM], it is the fact that we are eating foods made of junk, that is far more dangerous I think. This is something we were talking about yesterday at this conference; it's a difference I've noticed working between the US and Europe, where in Europe "everyone" is terrified of GM, whereas in the US, people seem to be less concerned at a national level. The conversation is less extreme, but then, conversely, there many people don't believe in evolution.

How do you even assess a technology as citizens when you don't even believe in the fundamental science that makes it possible? We were discussing this yesterday; we were wondering how design and education could be tools to explore that. This was a conversation with someone, who—for context—lost a group of friends in the Paris attacks, and now wants to shift towards education. He's asking how you reach people who don't even believe in science, but religious ideologies? How can you innovate education around these basic ideologies [of what is better]? That's how that came up. There seems to be a very important area there that I don't know even how you get into...

DE: As always, when that topic arises, I often return to *Pedagogy of the Oppressed* by Paulo Freire. In his experiences in education, I believe it was in bringing mathematics to rural agricultural workers in Central and South America, he discovered that the piggy bank model, where the teacher declares the relevant knowledge and then demands that it be inserted into the brains of the students. "I'm gonna learn you this stuff, students!" which doesn't work, typically. And instead, replace that with an empathy-initiated engagement, what's relevant to the would-be learner, regardless of what I wish they might learn? And then from that, create on-ramps of relevance that enable and inspire the students to do the hard work of learning, not prescribing ahead of time what they must learn, but by having symmetry, enabled through empathy. It's really interesting to me that most of the online educational programmes seem to be deploying the piggy bank model.

ADG: Yes, MOOCS especially are promoted as novel and democratic. But it's learning by rote… this is what you'll learn… no interaction. I think that this idea of empathy, going back to the idea of countering industrialisation, how do the people who are industrialising it, how do we bring in these other value systems? Everyone is excited about Open Plant because it seems to present a different set of values. Are there models; are there ways that we can use design and/or collaboration with synthetic biology to induce that empathetic feeling?

DE: Well, I think that the answer is, "Yes." I think that iGEM provides a lot of solid examples of that. I think of the team in Paris, supported by the Bettencourt Foundation that was working in the context of nutrition in the south of India, and comes up with an awareness of the locally-produced breakfast bread, idli, which is typically made on a per household basis, within the house. They go, “Wow, there’s probably some yeast in there. And that means that we could change the yeast, or change the strains.” And they looked at both, and the application was vitamin biosynthesis—vitamin provisioning in the diet—which was also chosen because it was relevant to that location. I think the thing about biology is that it occupies niches everywhere. Which means it is everywhere, so it’s right on the frontline of the diversity of needs for people, and so provides an opportunity for design to identify what biology could do on a distributed, local, and individual basis. I think that the alternative could be to see a sort of industrial design applied to synthetic biology, that doesn’t ever develop a recognition of the plurality of contexts and possibilities, that it’s declared certain things that the industrial engine must be sourced on a sustainable basis. The designers will figure this out and what it will be used to make. But it won’t ever leave that industrial frame. The more that design can get out the periphery and into the individual layers and contexts, the more that I think that we will understand the amazing, almost infinite, number of opportunities. I don’t know, there is also a question, returning to your theme of better. Sometimes design gets deployed in ways that lead to homogeneity…

ADG: Oh, absolutely!

DE: And other times, design gets deployed in ways that promote heterogeneity and diversity. I guess I don’t know enough about it, Daisy, I’d be curious if it’s understood: are there examples of things that could have gone either way? We got one type of culture, or ecosystem, rather than the other? And if so, what were the drivers or levers that resulted in that?

ADG: I think increasingly — that’s a really good question that requires more thought — but the model that we conform to now is homogeneity, a love of the mass-produced object and that has become the absolute standard. There are design movements that try different things. I think architecture is different, because architecture is about the prototype in effect, every building is different, and is more context-dependent or aware in general. Movements such as maker movements, or fixers, and in India, “jugaad”, a hacking movement, those are spaces that generate authentically diverse design. Whereas mass customisation and the things that we see now masquerade as heterogeneity. I don’t think it is something that is celebrated in truth. Increasingly, we are seeing and recognising it. Even in the conversations at the DLD [2016] conference around the future of food, it had to be said that these were problems that wouldn’t be solved in Silicon Valley; they would be solved by people who understood food. Food is not a technology, technology can assist it, but it is a business and process problem. Distributing calories is the problem, and making those better calories too. Localisation is the best possible way. In a similar way in design, the idea of diversity and local solutions come to the fore. It would be a good trend to pursue, but this isn’t the mainstream idea. Design has gone down a different route. The fact that my computer is made in China, that we celebrate its simplicity, only helps to perpetuate that idea further: masquerading as simplicity, but really complexity, that mass customisation is the same as heterogeneity. “You can have any colour as long as it is black”, as Mr Ford said a long time ago.

One last, difficult question for you: as someone who creates imaginaries and visions around synthetic biology to make it happen, that’s one way I see the importance, alongside the science of what you do: “It could be like this”, “This is what we strive for.” How do you see that role? Is that a difficult role? Something that I’m really interested in is how we create imaginaries and visions of better, so how important is that, do you think, from your experience, such as the BioBricks Foundation creating “Biotechnology for the public good”?

DE: Uhhh… The simple response is all those sorts of things are essential in the context of struggling to understand what is wished for, and then to make that possible, or just make it.

I think that a critic of that position could fairly say, you know you’re just wasting energy on that stuff. Much better just to make things and make things real, and everything else will sort itself out. But I think in practice, unfortunately, our experience has been, that if you don’t construct dreams and cultures, that the practice will always relapse to the past or the status quo. The simplest example that I could give would be in the early days of iGEM. I mean like the first time we went to five then thirteen schools. We would always have this team from Princeton that was led by Ron Weiss, who was one of Tom Knight’s—the inventor of BioBricks, that Tom—PhD students. And they would show up, and they would give a great talk about their project, and in their talk they would declare all these amazing new BioBrick parts they had made. Just unbelievable, just so much work they had done down in New Jersey.

So the competition would end, and everyone would go away. We would go, “Oh, so where are all those parts?” And they were wiling to get up in front of the community and to say that they had made all these BioBrick parts, but they weren’t then that willing to share them with anybody, because of proprietary competitive advantage due to Princeton. And that continued. And it was really baffling, because this was Tom’s student. And the only way we fixed that was not to have a conversation with Ron about, “Hey. Could you do the right thing?” Or like, “Hey guys…” That wasn’t the right solution, that wouldn’t work. The solution was to create judging criteria that explicitly encoded in practice the value of the community, which was sharing: giving and getting. So that if you wanted to be eligible for earning a silver medal, or a gold medal, you had to comply with the requirement of physically contributing at least one BioBrick part for use by others in the future.

So I think it is essential to imagine alternate futures and paths for realising them, and to implement mechanisms or nudges that promote getting there, eventually. It feels a little bit lonely, which is fine...

ADG: That’s exactly what I’m aiming at. There are two things I’m looking at, that design can be used to imagine alternative visions of better, and that design can be a tool to understand the values that shape “better” or multiple betters. Through that process — where you experimented to find what is the nudge, what is the tool you need, then it shapes a community. I couldn’t believe the photo of iGEM last year, that it was 5000 students! But do you think this can work on a bigger scale, on a policy scale?

DE: Oh, I don’t know. You know, how do you promote, reinforce or transition to a culture of citizenship versus a culture of compliance? I don’t know. I think for me as I have wrestled with some of these topics, a few of them end up getting to a good spot. For example, specific to the sharing of parts, and free to use BioBrick parts. Effectively what we are in the early days of is organising a language of functions that can be invoked to realise human intentions in organisms, in living matter. So languages, if you just stop and think about the history of languages, broadly, you can discover some pretty amazing statistics. Languages for translating human intentions into electrical computing machines. Lots of them. And what happens to those languages over time is that they tend to become either used or they go extinct. Twelve of the fifteen most used electrical computing programming languages are now free to use, today. And there are a variety of drivers that select for that. I can gain a type of comfort in that, “Oh, I happen to be very early in developing a language for translation of human intention into living matter.” It is inevitable that the successful languages will become free to use, hence my email signature, “Our victory is inevitable, our timing is uncertain.” I don’t know how long it will take. I can then guide actions to accelerate the transition, and then take some comfort that it will be realised eventually.

ADG: That’s really helpful. Thank you for crystallising those thoughts! So, thank you for your time. And I hope we can continue the conversation. Or may be we’ll all be industrialised by then!

DE: Maybe we already have been.

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