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Marin Sawa

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This paper describes and reflects on an empirical account of the scientific research laboratory as a place to work for a designer in biodesign practice.

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There is a recent trend for designers to access cutting-edge biotechnologies such as tissue engineering and synthetic biology by collaborating with scientists in the research laboratory. These collaborations can be long-term interactions, such as Rachel Armstrong and her architect colleagues with the synthetic biology laboratories based at the Centre for Fundamental Living Technology, the University of Southern Denmark,[1] but more commonly they operate on a short-term basis from a few days to a few weeks as in the Material Beliefs project at Goldsmith University,[2] the Synthetic Aesthetics residencies project initiated at Stanford University,[3] and the design research initiatives at Cambridge University.[4] These short-term collaborations typically introduce designers to the laboratory in the form of an 'observation day' to understand the scientists' expertise and research.

Interactions are also common at later stages of applied research in developing commercial applications.[4] The more extreme example of designers establishing their own lab space in science institutions is rare but has been demonstrated by SymbioticA run by Oron Catts and Ionat Zurr based at the Art and Science Collaborative Research Laboratory at the University of Western Australia.[5]

Such work exemplifies the collective emergence of what design historian William Myers later formalised as 'biodesign'.[6] This term previously appeared in an exhibition catalogue written by art historian/curator Caterina Albano in her observation of biodesign exhibits in relation to bioart: She observed 'an intriguing and perplexing projection of the potential application of biotechnological developments' and the conceptual character of biodesign in relation to the commercial orientation of mainstream product design.[7]

Although there have been first-hand accounts of the laboratory by sociologists such as the field studies conducted by Bruno Latour and Steve Woolgar in a Salk Institute biochemistry laboratory[8] as the means to understand scientific and technological contents,[9] and by Paul Rabinow on a biotechnology R&D laboratory,[10] there are relatively few practical accounts by designers on the results of their laboratory practice, and even fewer on the actual designer's experience of the laboratory environment as a place to explore, experiment, and design collaboratively.

This article summarises my first-hand experiences of working as a biodesigner on a daily basis in a university research laboratory as a central part of my PhD. The research was conducted with the aim of developing new applications for microscopic algae in the context of the urban environment. My earlier design experimentation with microalgae demonstrated the possibility that living organisms act as the basis of a design strategy, both aesthetically and functionally.[11] These single-celled photosynthetic organisms grow using sunlight, water, and atmospheric carbon dioxide and are currently the focus of various research efforts including the production of renewable fuels, high-value chemicals and also health foods. As a technology, microalgae are at various levels of realisation from emergent laboratory scale to pilot studies and through to commercialised products. My focus was on exploring a new surface form of algae cultivation for potential interior installation, moving away from mainstream liquid culture, in order to domesticate biotechnological applications of microalgae, with an emphasis on energy and food production.[12]

The choice of collaborators

My exploration for biotechnologies and functionalities of algae necessitated strong collaboration with expert scientists in algal research. In my case I formed a close research relationship with academics at Imperial College London engaged in various fundamental aspects of algal research ranging from solar energy conversion to the production of algal biofuels, such as hydrogen gas. The choice of Imperial College as a potential collaborator arose when I came across an algal growth chamber or photobioreactor made by the Imperial College Energy Futures Lab on display in the Antenna Zone in the Science Museum in the summer of 2010. I found the point of contact, Professor Nigel Brandon, the then Director of the Energy Futures Lab, and following a short meeting where I described my research aspirations, we agreed to embark on a

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collaborative project within a PhD research framework to explore the unforeseen potential of growing algae on interior surfaces.

The scientific collaboration gave me a unique opportunity to work with Professor Peter Nixon and his group of biochemists in the Department of Life Sciences, and Professor Klaus Hellgardt and colleagues in the Department of Chemical Engineering. To speed up communication and collaboration, I opted to move from my studio to the Biochemistry lab, with the informal title of Designer in Residence, where I carried out my practice-based PhD research for the next three years (2012–15). The combination of being embedded in a research group and practising intersectional work with research scientists gave me an intimate insight and experience of the laboratory and their daily activities, far beyond those afforded by interviews, literature review, workshop, a short-term residency, or even long-term participant observation.

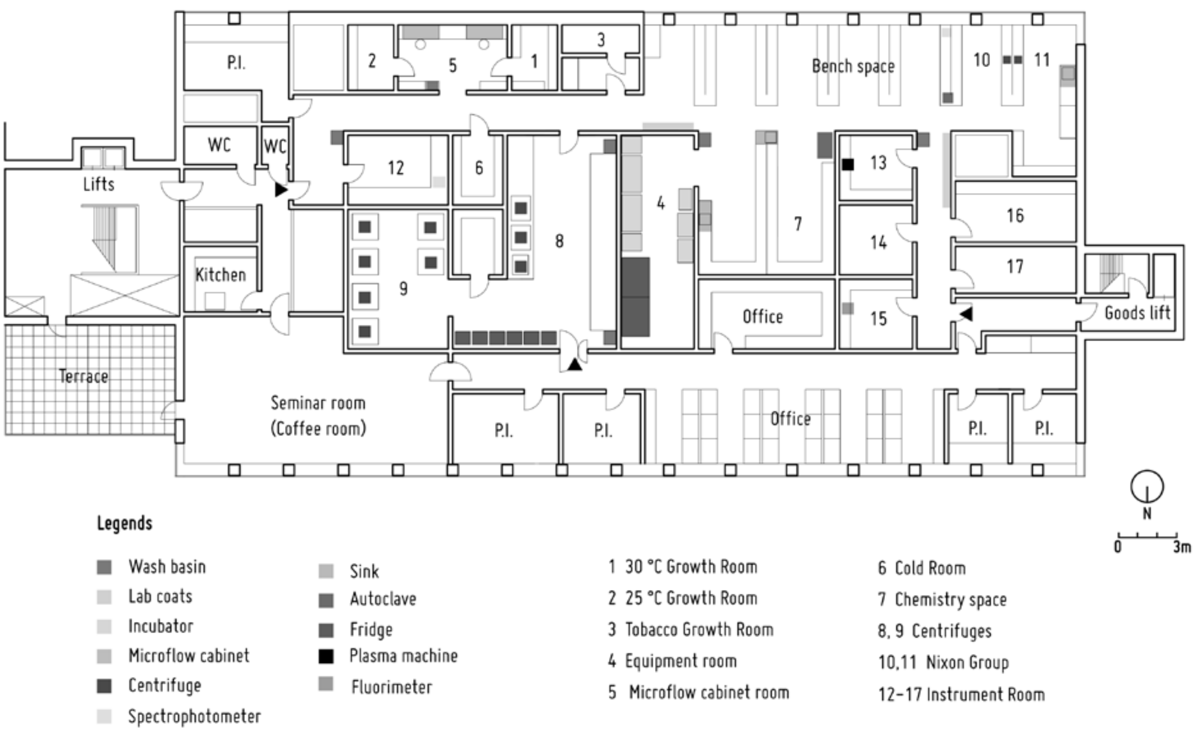
Working in the laboratory

The biochemists work in the Photosynthesis Research laboratory on the 7th floor of the Sir Ernst Chain Building – Wolfson Laboratories at the South. Kensington Campus of Imperial College London. As Professor Peter Nixon explained, the 7th floor was originally the home of Nobel Prize winner Sir Ernst Chain and his family when he was the first Head of the Department of Biochemistry at Imperial College in the early 1960s. Subsequently it was converted from a flat to a working lab in the early 1990s and in the 2000s was completely refurbished into a modern bioscience laboratory. Like the other floors of the Sir Ernst Chain Building, the 7th floor is segregated into laboratory and office areas, with strict rules in place to make sure the office area is a safe place to eat, drink, and write. Next door to the office area are a seminar room that doubles up as the Departmental coffee room, a small kitchen, and toilets *[1]*.

Strict regulations are also enforced when working in the laboratory to ensure that researchers can handle biological materials and chemicals (including hazardous reagents) in a safe manner. These include security-controlled access to the labs, extensive laboratory training and safety induction, access to appropriate equipment, the wearing of lab coats, safety glasses and disposable gloves, and the prohibition of eating and drinking. All chemical and biological waste is disposed of in carefully regulated and controlled ways to avoid contamination of the environment outside the laboratory and harm to life. In the case of the Photosynthesis Research lab, four research groups each led by an academic (or principal investigator) and comprising postgraduate students and postdoctoral research fellows, share the space and the facilities. At the heart is the open-plan bench space area where the researchers do much of their experimental work. Around this space, in easy reach, are instrument rooms containing specialised pieces of equipment and constant temperature growth rooms optimised for the cultivation of plants, microalgae, and related cyanobacteria as well as walk-in cold rooms used for downstream activities such as protein purification and other areas for protein analysis and measurement of photosynthetic activity.

As indicated by the floor plan, there are four independent culture rooms (labelled 1–4 in *[1]*): the 30°C and 25°C growth rooms for growth of cyanobacteria and algae in liquid and solid cultures; the so-called 'Tobacco' growth room which is

1 Floor plan of the Photosynthesis Research laboratory located on the 7th floor of the Sir Ernst Chain Building, Department of Life Sciences, Imperial College London.



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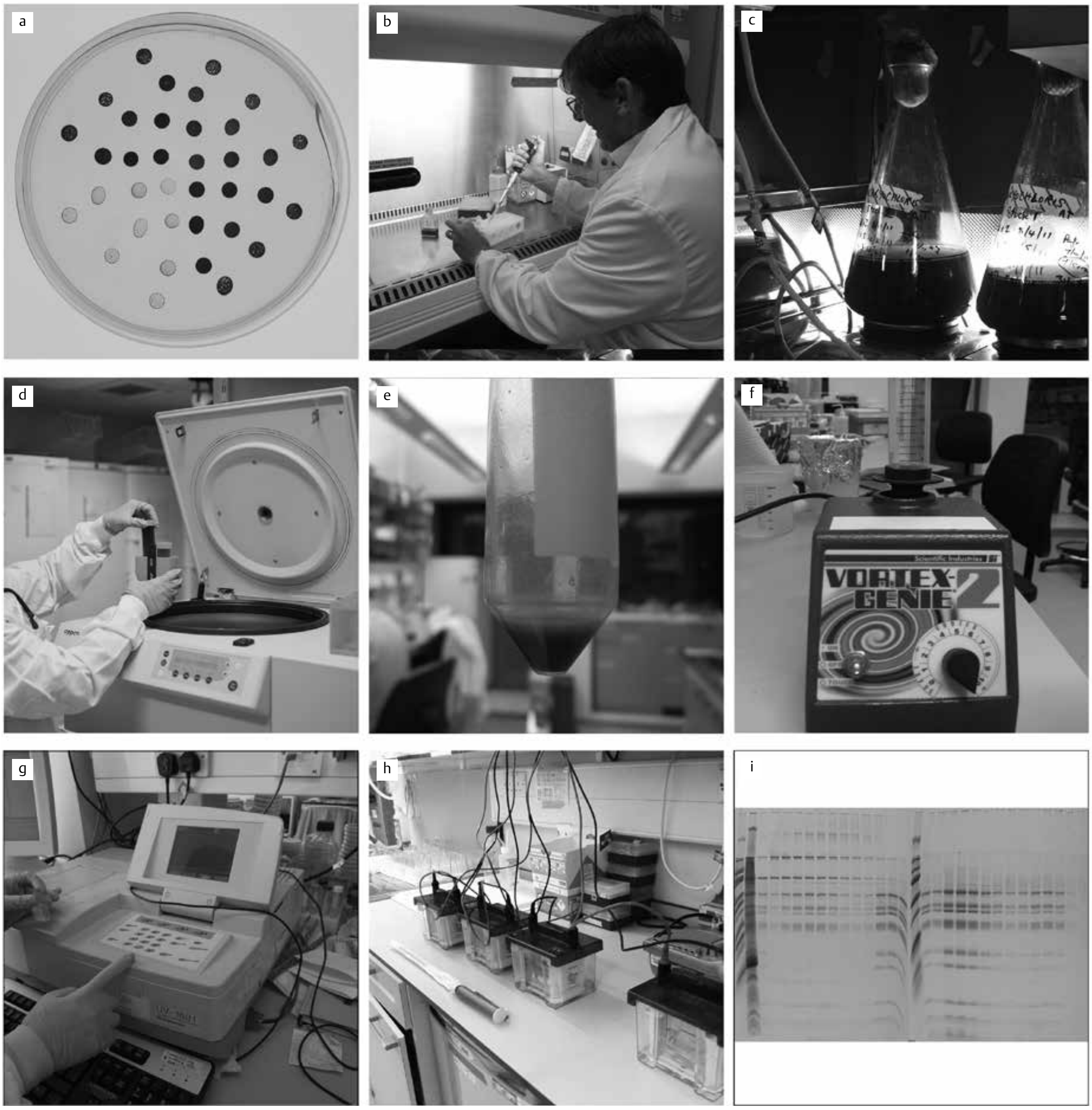
maintained at 26°C under continuous illumination for growing tobacco plants and the so-called Equipment Room which accommodates 45°C illuminated incubators for the growth of thermophilic (heat-loving) cyanobacteria. These constant-temperature environments enable the growing of algal material for scientific experimentation in closed systems under optimised, highly reproducible and controlled conditions, far more efficient and versatile than my own attempts at growing algae at home. The emphasis of the scientific method on measurability, reproducibility, and purity extended to all aspects of lab life including the aforementioned controlled artificial environments, experimental protocols, chemicals, and biological material.

Scientific experimentation

The lab space has been designed for efficiency as well as safety so that the researchers can move from location to location in a highly regimented way to carry out their systematic experimentation [2]. For instance, cells from an agar plate [2a] are used to inoculate a liquid culture within a *microflow cabinet* [2b] in a sterile environment, which are then grown close by in growth rooms [2c]. After growth, cells are harvested using *centrifuges* [2d,e] then broken open, often using glass beads and a *vortexer* machine [2f] to release DNA and protein. The optical properties of samples are measured using bench-top *spectrophotometers* [2g]. Following protein purification, the composition of the sample is assessed by *Gel electrophoresis* [2h] to give rise to a stained *protein gel*, which gives molecular information on the complexity of the sample [2i].

The final electrophoresis step separates proteins on the basis of size to give a highly abstract yet ordered image of *bands in lanes* [2i] that can be only deciphered by experts. Latour and Woolgar would call this last machine an ‘inscription device’ that



2 Photosynthesis research facilities used for protein purification. *a* Cyanobacterial cells on agar plate. *b* Professor Nixon using a micropipette at a *microflow cabinet*. *c* Liquid culture of cyanobacteria. *d* A benchtop *centrifuge*. *e* Pelleted cells after centrifugation. *f* A *vortexer* machine for breaking cells open. *g* Spectrophotometer. *h* *Electrophoresis* tanks used to separate proteins. *i* Stained *protein gel* showing protein bands.

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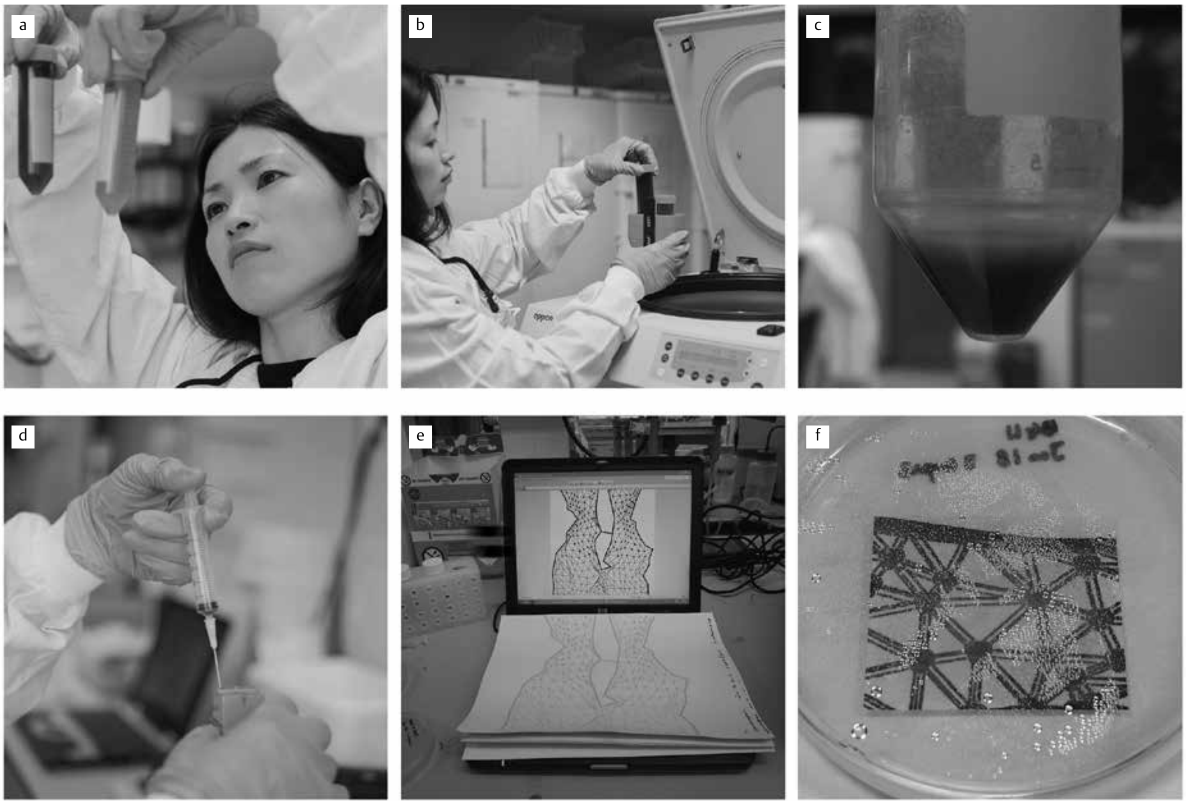

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3 The designer using lab facilities for her biodesign experimentation.
a Preparing cultures for centrifugation.
b Placing samples in centrifuge.
c Pellet of cells.
d Using a syringe to inject *bio-ink* into a modified cartridge.
e Printed cells plus image on computer screen.
f Growth of printed cells.

‘transforms material substance into a figure or diagram which is directly usable by one of the members in the office’.[13] Research on the 7th floor also includes the determination of protein structures using X-ray crystallography. Protein crystals made in the lab are taken to the Diamond Light Source in Harwell, Oxfordshire, for X-ray analysis, which leads to the production of a diffraction pattern that can be interpreted in terms of an atomic structure in three-dimensional space.

Overall the algal research on the 7th floor reduce single-cell life forms to smaller macromolecules to understand molecular structures and functions. As the biologist Edward Wilson observed:

> *The cutting edge of science is reductionism, the breaking apart of nature into its constituents. […] Complexity is what interests scientists in the end, not simplicity. Reductionism is the way to understand it.*[14]

Much of the subsequent analysis of data and drafting of scientific manuscripts for publication in peer-reviewed scientific journals take place in the office area. This spatial separation between the process of making and the process of reflection contrasts with the studio of the designer where thinking and making often coexist and coevolve in one space.

The designer in the lab

Like all new researchers to the lab, I was allocated a small area of bench space to conduct my experiments. The lab bench is a counter about 0.9m high, at which work is done mostly standing up, surrounded by small benchtop experimental instruments (such as in *[2]*), above which are shelves for storing bottles of media and so on. Although the bench space was rather cramped, this was the only area with views and natural light in the lab and I benefitted from being in close physical proximity to other researchers working in the open lab, which generated unexpected flows of communication and a collegiate behaviour that fostered collaboration and help with experimentation. Basic conversation was about the use of lab equipment. Dialogues between science and design nonetheless occurred in action-oriented, material-mediated ways, led by my non-standard scientific questions. The collaborators’ responses would help shape the next move often in a direction that had not occurred to me previously. I was also allocated a desk in the office area, which gave me not only space for my own reflection, but also exposure to the flow of informal discussion with others in the office.

These early conversation-based collaborations helped focus my research work on using an inkjet printer to print algal cells. The artefact demonstrated to the scientists for the first time a new method of extremely precise cell deposition technology for patterning algal cells on solid surfaces. Their positive pragmatic response quickly brought me credibility within the lab and enabled greater access into the experimental place, the laboratory, to develop this method in order to improve the quality of the cell suspension (called *bio-ink*). The process of preparing the algal bio-ink was based on protocols already developed by the biochemists for protein purification [2]. A homogeneous cell suspension of high cell density and pigment concentration was obtained by pelleting cells from a liquid culture in a centrifuge and then resuspending in a small volume of liquid which was injected into a modified cartridge [3a–d]. In practice, the choice of cell (algal species) was dictated by availability (quantity and quality of cultures) at the time of the experiments. Two model organisms, the cyanobacterium *Synechocystis* sp. PCC 6803 and the green alga *Chlamydomonas reinhardtii* were already available in the laboratory and could be grown to a high cell density and tested. Other algal species that I obtained from culture collections were often slow growing and more difficult to use as bio-inks. Knowledge transfer through daily conversation with my scientific collaborators was an important means by which I could overcome technical problems (such as clogging of the cartridges and poor cell viability) encountered during the process of printing. Their understanding of cell anatomy, such as cell shape and cell size, as well as tacit knowledge of growing *healthy* cultures proved instrumental. Finally I was able to identify conditions to permit successful printing of live cells in what I have termed *Algae Printing* [3e–f].

Algae Printing and the domestication of algal biotechnology

The experimental process of printing led to the emergence of the concept I call the 'domestication of algal biotechnology'. This design concept connected the digital printing of algae with cultivation of algae as bio-ink in small bioreactors for indoor installation. For cultivation of the bio-ink, the photobioreactors used in Professor Klaus Hellgardt's lab in the Department of Chemical Engineering proved to be particularly inspirational for my thinking in this area. One particular type, a bubble column system [4a], served as a reference point for the form and function of an aesthetic photobioreactor [4b].

I translated the laboratory-based biotechnological proof of concept into a design concept prototype for a spatial installation entitled *Algaerium Bioprinter* [5a], which was exhibited within cultural frameworks such as at the Anthropocene exhibition, in Warsaw, 2015 [4b] and the Alive exhibition in Paris in 2013 [5b].

Algae Printing in the domestic environment opens up the possibility of empowering the consumer by providing direct access to biotechnological algae and their applications without the need to involve industry. Potential biotechnological applications include the production of bespoke algal foods of high nutritional content, the generation of electricity using bioenergy wallpaper, or the cleansing of air by removal of carbon dioxide.[15]

In contrast to current practices in algal biotechnology, which are rooted in modern scientific research and largely motivated by a technocratic response to world hunger,[16] the depletion of fossil fuels,[17] and the rise in greenhouse gas emissions,[18] the *Algaerium Bioprinter* offers an ecosophical dimension, as articulated by Félix Guattari, at the intersection of environmental, social, and subjective (mind) domains.[19] The ecosophical concept envisions 'a reconstruction of social and individual practices'[20] through both scientific and aesthetic embodiment. In the case of the *Algaerium Bioprinter,* the *algal species* falls within the environmental domain, *technoscience* within the society domain and the *do-it-yourself* mentality needed for domestic printing within the subjective domain.

Reflections on the collaborative process

Looking back, the invention of *Algae Printing* was an important catalyst for my integration into the research team and the laboratory as it required me to use the lab facilities at a relatively early stage of my PhD project. This gave me the time and space to interact and understand the scientists' knowledge and methods and to become a fully integrated member of the research team through laboratory-based experiments. It also gave my collaborators a greater opportunity to understand me, the designer, and my methods. Literature acknowledges the importance of 'mutual understanding of each expertise' in interdisciplinary collaborations between designers and scientists[21] and in my case this developed in the laboratory, at the intersectional process of both using and making where knowledge and methods of the scientists were synthesised in the

4 *a, b* **Translation from a research model system (left panel) to an aesthetic photobioreactor design displayed at the Anthropocene exhibition in Warsaw in 2015 (right panel).**

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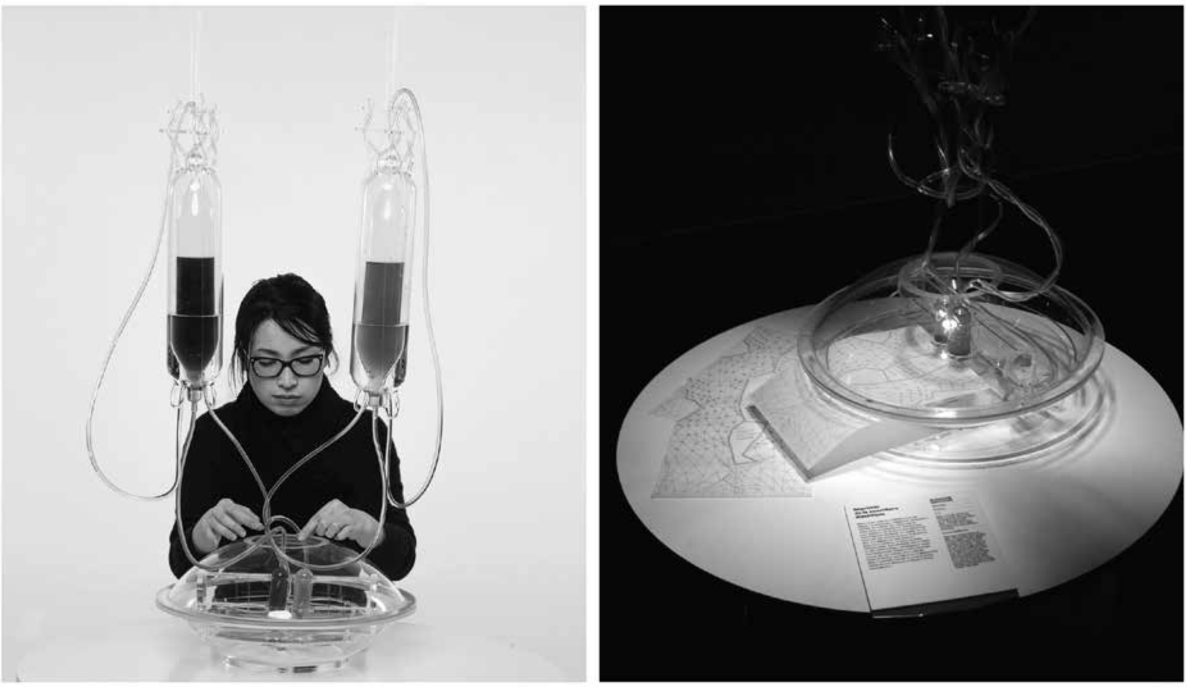

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5 *a, b Algaerium Bioprinter*. The experimenter and her laboratory-based concept design prototype containing liquid cultures of green and pink algal species with health benefits (left panel). Close-up of the bioprinter concept prototype with examples of digitally printable algal food supplements (right panel).

incremental, daily act of designing. The building of synergy in the collaboration was founded on common interests but the building block was complementary expertise and praxis.

A second important consequence of my long-term laboratory-based experimentation was that I picked up the scientific theory and scientific terminology underpinning my biotechnological work. The lack of a common language has been recognised as a potential barrier to collaboration between designers and scientists.[22] The designer's ability to understand scientific language is therefore considered particularly necessary from the scientists' side if the designer was to get involved at the level of pure research.[23] Interestingly, the beginning of my collaborative process benefitted from the lack of common language, which led to open-ended discussions and lateral thinking that spurred brainstorming conversations. However, an understanding of the formal language became more and more crucial as the collaboration developed through joint experimentation that blurred the boundary between designer and scientist. The co-writing of a scientific research paper on our design-led outcome towards the end of my research was a definitive learning curve of formal language.

Much of my dialogue with scientists was informal in line with Latour's previous observations that, in the laboratory, 'informal communication is the rule. Formal communication is the exception, a posteriori rationalisation of the real process.'[24] The flow of everyday communication made hard science more accessible to a non-scientist. Conversational communication revealed to the outsider a translation process between conjectures in the molecular domain and 'inscriptions' from the laboratory-produced photosynthetic cells. The biochemists and molecular biologists would discuss molecular space, structures, and mechanisms of solar energy conversion, involving protein macromolecules, chlorophyll pigments, light absorption, and the ejection of electrons and protons. This laboratorial exploration of functionalities of algae meant an experience of 'an empiricism of the virtual' by which Manuel DeLanda[25] describes scientific praxis that detects physical processes of molecular, atomic, subatomic entities. The flow of information between hypothetical experiments and hypothetical thinking characterised the intersection of empirical thinking from the lab and rational thinking. As Paul Rainbow observed, the design of the laboratory prioritises the flow of communication over interior décor,[26] the cluster of spaces such as the kitchen, coffee/seminar room, or even the terrace around the research lab are designed as if they were on the same plane of consistency and uninterrupted the concurrent flow of empiricism and rationalism.

Literature advises designers to seek open-minded collaborators.[27] A level of open-mindedness was most necessary at the beginning of this project, especially from the scientists, when we embarked on a seemingly abstract and ill-defined investigation some distance from the scientists' normal areas of research. Open-mindedness was tested when we sought a value of the outcome – whether scientists may or may not consider the outcome interesting. My unique experience here is that it required some tenacity from the designer before mutual confidence in the outcome was built. This was partly because the interdisciplinary outcome, even though very relevant, did not quite fit into the collaborators' fields of expertise. To contextualise *Algae Printing* into scientific research meant broadening the scientific references to include tissue engineering, biosensors, and phycology. Exploratory material-mediated thinking within creative research can naturally be expansive as it, Paul Carter writes, allows 'the unpredictable and different situation to influence what is found'.[28]

It is tempting to assume, and to hope, when surrounded by scientific experts, that the project is in safe hands and will naturally be driven forward as part of the research activities of the group. This is sometimes a flawed assumption and I found it essential to play an active role in driving the project forward not just in the process of making but also regarding literature review and publications. At a basic level, scientists are already extremely busy working on funded research projects with defined goals or milestones and with usually insufficient resources. The ability to divert time and resources to a new collaborative project, in the absence of funding, is therefore difficult. Scientists themselves expect the designer to drive the project forward and are usually unperturbed to act as facilitators rather than drivers.

A common perception, possibly with a hint of truth in the past, was that university research was rather inward looking and the main goal of scientists was to derive pure knowledge for textbooks and research papers. In fact, I found that my scientists' teams were eager to explore collaborative projects that potentially could lead to applications of their research in the wider world. In part this has been driven by changes in the funding landscape that now expects scientists to justify the applied outcomes of their work. But, for many, seeing an application to their research is a great motivation and a significant barrier for some scientists is to see how their research could be applied.

A role for the designer in research

Collaborations between designers and scientists are often viewed as one-sided with the designer the minor partner.[29] My long-term laboratory-based collaboration demonstrates the feasibility of a true 'two-way collaboration' in which design helps shape scientific research, not just apply it.[30]

Designers are actually well placed to act as intermediaries to link researchers to the wider world. In my case, I could see that there was potential to use algae in domesticated applications of potential interest to consumers far removed from those discussed by scientists which focus mainly on the biotechnology sector. In a sense, the designer by working closer with scientists offers a different link between the outside world and scientists. Social crises of the time provide a context for the designer. The designer is often inspired by technoscientific stimuli from scientific research (such as on algae) and is well placed to explore a range of applications and possibilities often free from scientific constraints, but which can be the spur for future detailed scientific work.

A designer is therefore important not just for exploiting the technology but also shaping it. Design thinking and scientific experimentation, together, can be effective in producing new models and new approaches by introducing flexibility into the rigidity of scientific research and industry. Co-invention is possible for design researchers through long-term collaboration. Scientific experiments demonstrate new functionality and uniquely open up both realistic and speculative potential for applications. Taking an analogy from the evolution of algae from cyanobacteria,[31] the role of a designer in scientific research should be more endosymbiotic with the designer physically located within the laboratory.

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Author's biography

Marin Sawa is a London-based Japanese designer/researcher practising experimental design at the intersection with biotechnology. She has recently successfully completed her PhD research at CSM-UAL, which was done in collaboration with Imperial College London where she was a Visiting Researcher. She holds AA Intermediate (BA (Hons) in Architecture), RIBA part1 from the AA School of Architecture, MA in design from CSM, and has worked in practice at various architects and designers studios (including Kengo Kuma and Associates, Tokyo; Loop pH). Her research works have been internationally exhibited and published in the area of biodesign in particular.

Author's address

Marin Sawa
m.sawa@imperial.ac.uk