Necessity-the-Mother-of-Invention: Smart and integrated bioservices

(Rachel Armstrong)

Microbial Hydroponics rendering, courtesy Anna Vershinina, 2023.

The Necessity: reduce environmental pollution, energy need and greenhouse gas emission footprints of buildings and create positive impacts by upcycling wastes and reducing consumption

The Context

Modern building services such as heating, cooling, and lighting draw from resources that are separated into different supply streams e.g. water, gas, electricity. They are needed as modern homes are based on the architect Le Corbusier's idea of a 'machine for living in.' Supported by all kinds of machines, our modern lifestyles consume large amounts of energy, much of which comes from non-renewable sources such as fossil fuels. This contributes to greenhouse gas emissions and climate change, while also being damaging for the environment due to their waste generation, water consumption, chemical pollution, and habitat destruction. A new generation of building services are needed that enable us to become self-reliant in terms of resources and ideally, create benefits for the household and environment.

Being able to re-use resources within our habitats and living spaces is known as "circularity" where substances that are used to support our daily lives are renewed rather than wasted. This reduces waste and pollution, conserves natural resources, and minimizes the environmental impact of production and consumption.

The Challenge

Garbage is a side-effect of modern lifestyles, Image courtesy Freepix.

Modern lifestyles are based on linear modes of consumption, where 'waste' is always the end product of any resource use. This tethers us to the marketplace so we cannot be self-sufficient as we cannot produce any of the basic things that we need ourselves.

To become a truly circular system, our living spaces must transform waste into a range of useful products. We have plenty of waste to choose from. On average, a single-person household in Europe produces approximately 0.5 to 0.75 kilograms of organic waste per day, while a family of four produces around 2 to 3 kilograms per day. Many European countries have implemented waste management practices to establish resource circularity and reduce the amount of organic waste sent to landfills. These practices include separate collection of organic waste for composting or anaerobic digestion, which can make biogas. In some countries, such as the Netherlands and Belgium, over 50% of organic waste is already being separately collected and treated.

Making good use of our waste is nothing new. Since ancient times, households have used microorganisms to generate heat in homes through the use of biogas, which is a mixture of gases produced by the breakdown of organic matter, such as animal waste, plant material, and sewage, in the absence of oxygen. This process, called anaerobic digestion, takes place in a bioreactor and is carried out by a community of microorganisms that convert the organic matter into methane and other gases. Biogas was already used in some cultures as a fuel for heating and cooking. In ancient rural China during The Western Han Dynasty, 100 BC, biogas was drawn from naturally formed Fire Wells using bamboo as a collecting pipe. Later marsh gas sourced from lakes such as in Erhai, was used for cooking, lighting, iron-smelting, and salt-refining. While biogas development slowed down in the early 20th century, during the early 1970's many rural communities began to construct biogas digesters to provide energy, sanitation and fertilizer from their organic wastes.

The Invention/s

While bioreactors are commonly used in industrial and scientific applications to culture cells and microorganisms under controlled conditions, in order to produce pharmaceuticals, biofuels, and enzymes, they are not typically used to service homes. The potential use of bioreactors in contemporary homes is, however, being explored using a specific type of bioreactor called the Microbial Fuel Cell (MFC), which was invented by Michael Cresse Potter in 1911. Consisting of an anode that receives organic waste, a selectively permeable membrane that allows metabolites to pass to the cathode, and a natural anaerobic biofilm that excretes electrons, arrays of MFCs incorporated into our homes are set to transform building services.

Specifically, they can: a) treat liquid waste streams; b) provide a digital interface, called the biodigital that links the organic and informatic spheres; and c) create a means for metabolically programming hydroponics systems. These three possibilities are discussed below.

The Living Architecture project (2016-2019)

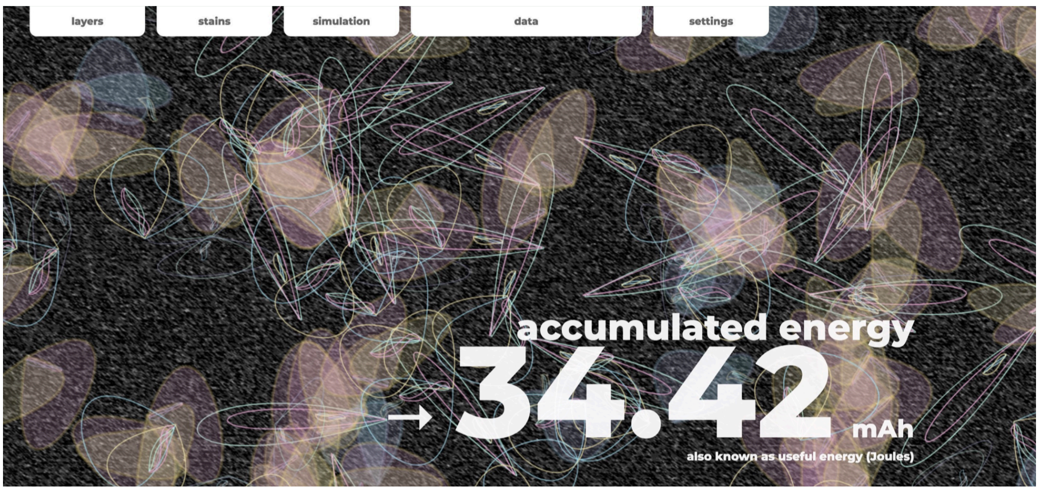
This research project developed a system of different bioreactors to process household waste within a circular building infrastructure. Drawing on different kinds of microbial metabolic activity in microbial fuel cells, algae bioreactors, and synthetic biology consortia, the bioreactors were organized so that the outputs of one type of bioreactor were the input for the next type, forming a circular system of exchange. The overall system provided a way of bioremediating and upcycling liquid organic waste into bioelectricity, cleaned water and biomass, while removing toxic nitrous gasses and recycling phosphate from household detergents (phosphate is a non-renewable resource – an important plant fertilizer – the supplies of which are limited).

A machine for living in,
courtesy of Rolf Hughes, 2023.

Living Architecture bioreactor 'wall', courtesy the Living Architecture consortium, 2019

The Active Living Infrastructure: Controlled Environment (ALICE) prototype (2019-2021)

This system developed the digital capabilities of microbial fuel cell arrays to visualise and interpret the electrogenic activity in their biofilms to reveal their extraordinary environmental intelligence by directly linking microbial metabolism with electronic systems. Electrical activity from the biofilm was a source of both power and data, which was translated into animations that conveyed the overall status of the biofilm. Participants could interact with the data in an exploratory exchange—as if they were caring for a pot plant, or even a pet—by feeding the microbes in the biofilms using a remotely operated valve system, or by gently warming them by turning on a remotely activated Light Emitting Diode (LED) in the laboratory.



"Mobe" data from ALICE, courtesy the ALICE consortium, 2021.

Microbial Hydroponics (2023-2027)

Microbial Fuel Cell (MFC) technology can also be integrated with hydroponics – the growth of plants without soil, just water – to introduce microbes in the biofilm to optimise nitrogen uptake, and mobilise phosphorous, averting the need for chemical fertilisers. This circular, sustainable platform turns carbon into biomass and reclaims nitrogen from wastewater streams with near-future applications in the home, gardens, agriculture and in the urban environment that anticipates and facilitates a healthier, sustainable, nature-based urban landscape.

Self-sufficiency using bioelectricity produced by microbes, courtesy Rolf Hughes, 2023.

While these applications are still in the research and development phase, they have the potential to be an innovative and sustainable solution for servicing our homes in ways that bioremediate our waste streams and take care of our local environment. The journey to market of MFC arrays for the household and buildings is still in progress and the necessary economies of scale have not yet been realized. However, it is likely that the collective impacts of household resources can be amplified when their value is considered at the scale of a local community, which will include provision for building operations within public (e.g., streets, hospitals) and commercial spaces. For example, a community could provide enough bioelectricity from unvalued organic matter to power mobile phones, provide LED street lighting, charge Wi-Fi transmitters, activate screen displays that enable citizens to access, for example, websites to online council services and even activate low-power robotics.

Creating an opportunity for citizens to make their own resources and use their homes as a productive site, is a significant stepping point towards activating an microeconomy, where waste streams are no longer forms of environmental contamination but become a shared and flexible resource.

The Significance

Neither optional extras nor an architectural fashion, microbial technology installations in our homes that perform circular building services will, literally, save lives. At a time of climate emergency, escalating fuel prices and the displacement of peoples from war, having access to basic utilities as a combined processing system can provide clean water, shelter, power, and sanitation, which maintains a basic liveability from freely-available materials, even *in extremis*. Additionally, electrogenic microbial technologies that can also provide food, take a significant step towards creative limits to domestic lifestyles that do not need more than 12V to perform any kind of housework. Becoming increasingly resilient and able to survive beyond centralized resource systems, in ways that bioremediate our surroundings might one day even exceed the quality of life that comes with a modern existence.

Potter, M. C. (1911). "Electrical Effects Accompanying the Decomposition of Organic Compounds". *Proceedings of the Royal Society B: Biological Sciences*. **84**: 260–76.

Libin, W. (1993). 2000 Years' Biogas Technology Development in China. Humanity Development Library 2.0: https://www.nzdl.org/cgi-bin/library?e=d-00000-00---off-0hdl--00-0----0-10-0---0---0direct-10---4-------0-1l--11-en-50---20-about---00-0-1-00-0--4----0-0-11-10-0utfZz-8-00&cl=CL2.23.14&d=HASH01d7a62b29576d5b3d1cde32.7.8&gt=1