DOI: http://dx.doi.org/10.7551/978-0-262-33027-5-ch002

How do the origins of life sciences influence 21st century design thinking?

Rachel Armstrong

School of Architecture, Planning and Landscape, Newcastle University, UK, NE1 7RU
rachel.armstrong3@ncl.ac.uk

Abstract

How can the origins of life sciences inform design thinking in an ecological era?

This paper considers the possibility of the origins of life sciences as being more than a blue sky practice for the development of advanced scientific theories but also offers a technical platform for designing and engineering life-like solutions for an ecological era. A design-led study of dissipative systems is discussed as a form of natural computing and innovation platform that can deal with probability and whose ontology (nature of becoming) is consistent with complexity, nonlinear dynamics and the flow of energy and matter. However, since the proposed approaches do not yet formally exist as products or mature technologies, exemplary design-led projects are introduced to explore the principles of design and engineering with these origins of life strategies. A portfolio of work is presented that includes the The Hylozoic Ground installation and Future Venice projects. Such experimental work investigates the value of collaborations between the origins of sciences and design practice as a strategic approach towards new systems such as, artificial soils – which may not only be recognised as applied research fields that offer insights into the transition from inert to living matter – but also give rise to potential cultural impacts and commercial opportunities in the built environment.

Introduction

We are in the midst of a transition from an industrial to an ecological paradigm of practice.

This is not as simple as making a substitution of an object-centered view of reality and supplanting it with process, complexity, networks and nonlinearity. Rather, it involves constructing a framework for understanding a world in continual flux that is navigated by many overlapping models of thought. This brings about paradoxes in the way that we work and solve complex challenges. The role of design in this quagmire of choices is to provide navigational avatars that can deal with inevitable inconsistencies when these models overlap, so that we may shape new values and forge new cultural practices.

At the heart of this transition is the appreciation that the world is in constant flux and that the matter from which it is formed – is lively. Responding to grand global challenges such as, climate change, increasing population density and the sustainability of cities, architects and designers have been looking for new ways of working with a whole range of strategies to counter the net effects of global scale, intensive industrial practices that are effectively reverse-terraforming our planet. Insights from the origins of life sciences point towards new opportunities in design thinking. Its quest is invested in the transition from inert to living matter – a complete reversal of the industrial paradigm.

Origins of life principles have actually pervaded design thinking with the rise of modern computing. Approaches that may be likened to information first strategies engage with many computer-modelling tactics, such as genetic algorithms and parametric design strategies. They generate a range of selectable objects that aim to resolve immanent forces within dynamic processes, which for example, have been applied in the work of William Latham (Latham, 1988) and Greg Lynn (Hight, 2007, p.43).

Metabolism first approaches are a more recent addition to the design portfolio and work directly with material self assembly and programmability, such as Autodesk's Bio Nano Programmable Matter research group that includes for example, Skylar Tibbits' work with 4D printing (Wakefield, 2013).

While origins of life sciences are generally regarded as 'blue sky' experimental practice with little, if any opportunity for technological innovation, recent collaborations between experimental architectural design and scientific research groups have opened up a potential range of applications with possible commercial value. While these cross-disciplinary approaches may still be some years away from becoming productised, a new portfolio of design language is emerging with an original ontology and epistemology that considers life itself as a technical platform and may fundamentally change our expectations of living systems.

Natural computing and origins of life sciences

This paper discusses a developing portfolio of design strategies within the field of natural computing to exemplify these

Rachel Armstrong (2015) How do the origins of life sciences influence 21st century design thinking?. Proceedings of the European Conference on Artificial Life 2015, pp. 2-11

approaches. Natural computing is a term that has been inspired by Alan Turing's interest in the technological potential of the natural world and consists of a range of overlapping scientific practices that range from the computer modelling of biological systems to working with programmable matter. It also shares many overlaps with morphological computing (Pfeifer and Iida, 2005) and unconventional computing (Adamatzky et al., 2007), which are also concerned with how matter makes 'decisions'.

Dissipative structures may be regarded as operative agents that can complexify space and matter. They function as an iterative system – or 'natural' counting process – that can be ordered to generate a range of programmable outputs. Jeremy England's notion of dissipative adaptation, as a possible complementary driver to evolutionary processes than genetic modification, is of particular interest as a generative and selective strategy when considering the transition from inert to living matter (Wolchover, 2014).

Dissipative structures arise spontaneously in nature across a range of scales such as, crystals, tornadoes and galaxies. While not all dissipative systems meet the technical qualifications of 'life' – all 'life' is a dissipative process. Those systems that are not given the full status of being truly alive are of great interest in the design process as a set of tactics that may increase the probability of life-promoting events. Potentially, when these spatialised material exchanges reach a certain degree of complexity, lifelike events may even be inevitable. Such substances sound mysterious, or even fictitious, but we can recognise them in everyday materials such as soils – on which all terrestrial life is founded. Soils represent an alternative material organising system than is used in our design processes today. Rather than being purified, homogenised and constrained within bounded spaces, they are open, messy and highly heterogeneous. This is of extreme interest in identifying processes that increase the liveliness of space and even raise the threshold of events that may spontaneously produce 'life' within a specific environment.

A series of design-led laboratory experiments demonstrate how such discursive systems may be constructed and provide a point of reference for thinking about how environments that support lively events – as opposed to designing life as a set of objects – may be approached as a way of producing 'artificial' soils that underpin fertile terrains, in which the probability of life is increased, using a set of simple techniques.

Generating dissipative structures

Dissipative structures may be produced at the intersections of mutually complexifying, active fields. This can be experimentally demonstrated using simple kitchen ingredients that provoke dynamic interactions. For example, water affinity can be used to produce a very simple dissipative system by harnessing the energetic and material potential that exists between substances that have very different relationships with water namely: glycerin that strongly attracts water and olive oil, which repels water. A base layer of glycerin and a top layer of olive oil create an interface at which droplets of food colouring are introduced using a hand-held pipette. Adding rock salt to the droplets increases their affinity for water, which provides further complexity and tension in the system. The hygroscopic properties of glycerin eventually overcome the osmotic pressure of the food colour droplets, at which point they explode downwards leaving structural trails in their wake that outline the resultant transient dissipative structure. Oil soluble coloring spreads sideways through the olive oil interface providing a residue of molecular activity – or, three-dimensional painting. Figure 1 is an installation for the On Architecture Exhibition at the Department of Arts and Sciences in Belgrade where food colour droplets have discharged into the base layer of glycerin leaving spidery threads of salt crystals behind. The technique is being prepared for use in secondary schools as a 'poor man's chemical garden'.[1]

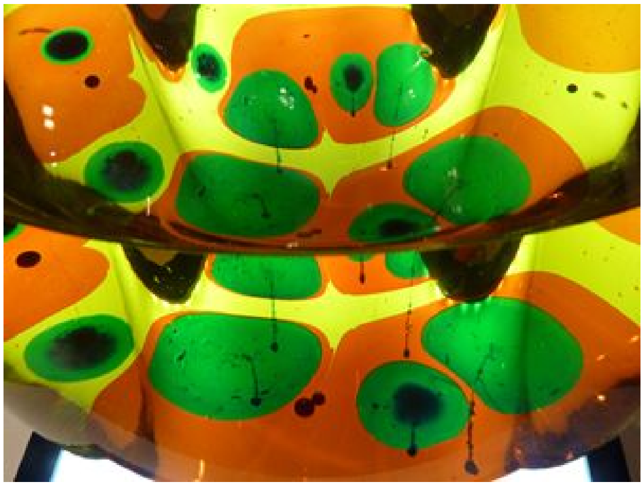

Figure 1: [Photograph by Rachel Armstrong, Academy of Arts and Sciences, Belgrade November 2013.] Oil and glycerin interface with table salt saturated droplets of food colouring. Exploded droplets leave crystalline trails as evidence of transient dissipative structures that emerge from the overlapping fields of activity in the experimental set up, which are competing for water availability.

Towards increasing complexity

Once potentiating fields of interaction have been established, the propagating waves of interaction produced by the os-

---

[1] Concern over the carcinogenic effects of crystalline salts, such as nickel and chromium, are becoming problematic for health and safety regulations. This 'edible' system therefore provides a highly colourful demonstrator for self-organisation without these regulatory challenges.

cillators begin to radiate and collide with each other. In reaction-diffusion computing, wave collisions have been used as tactics for establishing classical engineering strategies such as, logic gates (Adamatzky et al., 2005). Essentially this approach looks for events that can be translated and worked into mechanical circuits. In other words, complexity is being de-complexified so that it may be assimilated within a familiar mechanical engineering framework.

But what if an open-ended set of events within an environment are encouraged by starting at a rich and complex initial state as a way of preventing, or delaying the dissipative system from falling into a simple state – i.e. reaching equilibrium. Ikegami and Hanczyc (2009) call this approach the Maximalism design principle. The concept invites today's experimentalists to design more complex initial species of dynamic agents, where 'life' emerges at the edge of self-organisation and complexity. This theory is supported by England's observation regarding the dissipative adaptation of matter – that when a group of atoms is driven by an external source of energy (sun, chemistry), it will often gradually restructure itself in order to dissipate increasingly more energy. This could mean that under certain open environmental conditions, matter inexorably acquires the key physical attributes associated with life – and 'half-living' systems may emerge where bundles of self-assembling, mutually influencing bodies produce the conditions, and environments, of their own existence. Such complex events can be observed using Bütschli droplets, which represent an example of highly complex initial agents whereby each body influences its surroundings. The images in figure 2 are taken from a series of over 300 replicate experiments whereby lifelike events and organic structures with a range of striking morphologies and behaviours were produced within seconds to many minutes (Armstrong and Hanczyc, 2013).

Figure 3 shows an 'oceanic' ontology (Lee, 2011) of Bütschli species grouped according to observed morphological and behavioural typologies. The diagram represents the contextualisation of meta events between droplets with time within a complex field of activity. The stage is not a single reading of events but reflects multiple possibilities where the field of activity, is constructed through exploratory, graphical approaches. The resultant diagram maps relationships in the system rather than invoking the classical 'tree' metaphor of classification systems, which focuses on differences rather than similarities between actors. The graphic is centred at time zero, from which concentric circles radiate, representing an exponentially increasing series of time intervals. It depicts the intense self-organising activity that happens early on in the chemical reaction. An estimated 90% of chemical activity is completed within five minutes of activation of the system, although individual droplets have been observed to be active as long as an hour after their genesis. A spiral that represents complexity also radiates from the origin around which various droplet morphologies and behaviours that indicate change in the system are grouped subjectively. For example, 'oyster chains' are distinct in appearance but only differ from 'complex marine landscapes' by the relative degree of solid material they produce. The range of different bodies produced by the Bütschli system generates a potential portfolio and experimental starting point for 'soil-producing' technologies – fabrics and materials that may increase the material complexity and 'fertility' of a landscape and therefore the probable occurrence of lifelike events. Such systems do not have any direct commercial applications but do begin to suggest ways of taking a first-principles approach towards developing 'artificial' soils, or other life-promoting synthetic media.

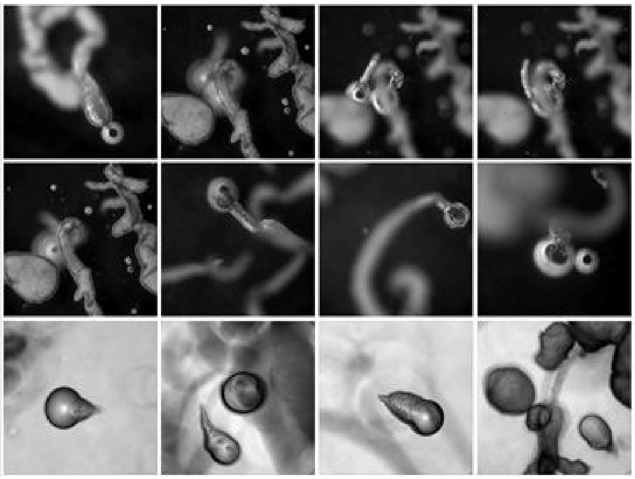

Figure 2: [Collage of movie stills by Rachel Armstrong, Southern University of Denmark, Odense, June 2009.] Range of osmotic structures produced by the Bütschli system.

Natural computing constitutes a platform that can facilitate entirely new design and engineering opportunities. These take the form of material convergences that exist within the entanglements of the spontaneous flow of energy and matter. Some of the lively bodies form loose, reversible groupings – or assemblages – with each other, while others become coupled and transformed by the interactions. Natural computing techniques also help break down some of the ontological barriers that set objects and systems in opposition and facilitates technological convergence whereby lively bodies may reach tipping points that produce radical breaks and discontinuities in the system.

Questions of scale

Unmodified Bütschli droplets spontaneously arise at the millimeter scale and last for many minutes. However, they can be easily made bigger and scaled to the centimeter scale as well as last longer, over a course of weeks, by adding an extract of their waste products to their body. Although these

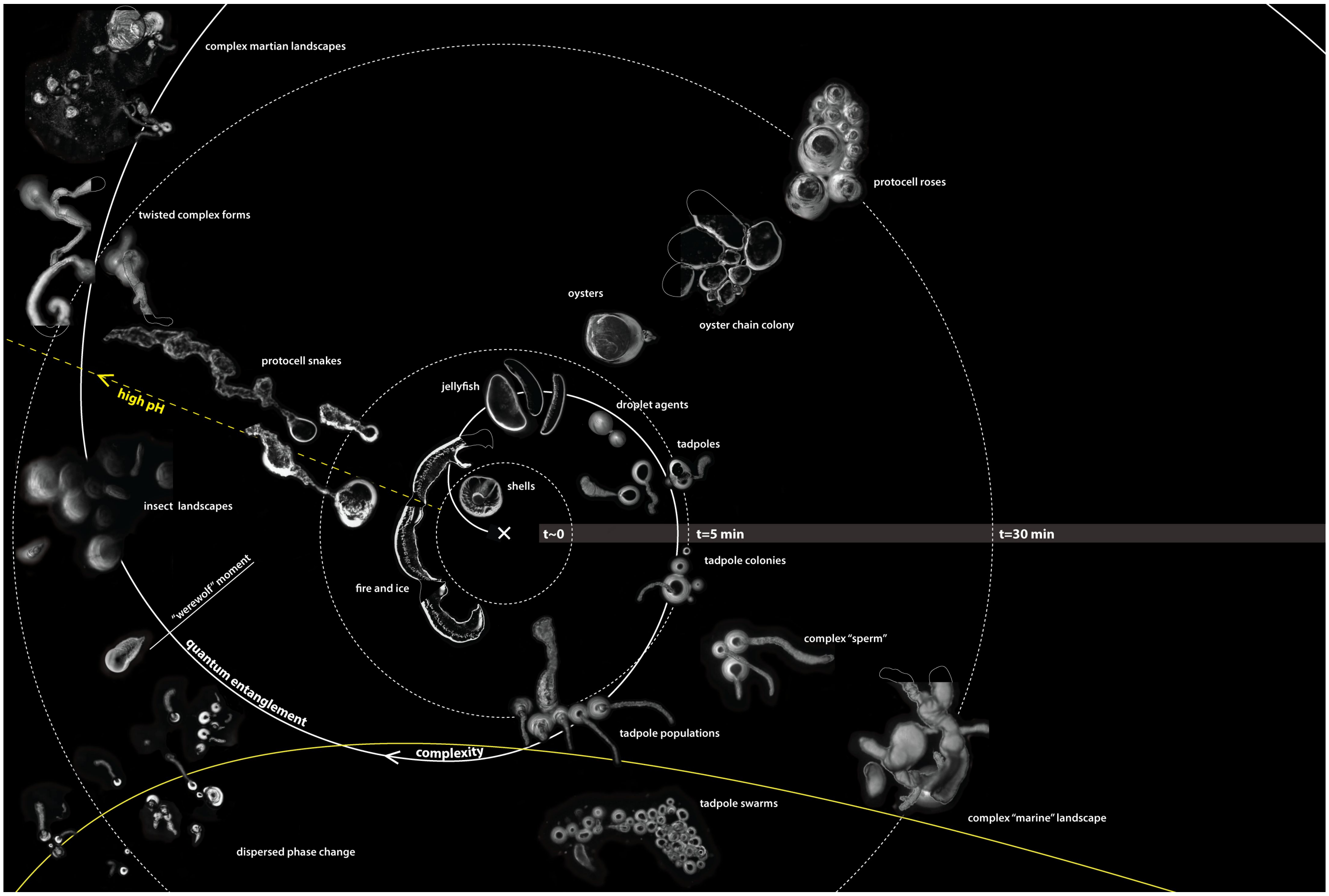

Figure 3: [Diagram designed by Rachel Armstrong and drawn by Simone Ferracina, July 2012.] This diagram depicts dynamic droplets as 'actors' that operate within the many variable influences encountered in their oil field as an ontolological 'map' of events. While the diagram is drawn as a 2D topology, the field events are manifold and open up multidimensional spaces through their continuous interactions that shape the evolution of the system.

agents are less lively than their original counterparts, they still possess the fundamental properties of dissipative systems. For example, in this attenuated form, they can be programmed to produce microstructures by adding salt solutions that transform soluble carbon dioxide into an insoluble carbonate precipitate (figure 4).

Physical constraints placed on the system can provoke a range of phenomena. For example Turing bands can be produced by reducing the physical dimensions of the reaction space to around 2 cm, which approximates with the maximum diameter possible for a modified droplet. These undulating configurations are the consequence of reaction–diffusion systems, which Alan Turing believed underpinned pattern formation in animals during morphogenesis, like dappling (Turing, 1952). This transformational ability was clearly demonstrated in this installation in Vienna at the Natural History Museum (figure 5). This design-led experiment suggests how environmental constraints can shape the outputs of complex self-organising systems and requires designers to consider the scale of operations and site-specificity of these systems.

Natural computing design programs

Once established, dissipative systems like the Bütschli droplets may be manipulated within a network of interactions between bodies by altering their internal and external conditions. However, such distinctions are over-simplistic as dissipative structures are inherently leaky and introduced events eventually influence the whole of a field through reaction-diffusion computing processes that can be shaped at multiple interference points.

Internal droplet modification

Bütschli droplets can be designed to create a range of different products – or secondary forms – by adding different chemistries to their internal environment. For example, microstructures may be produced at the oil/water interface by

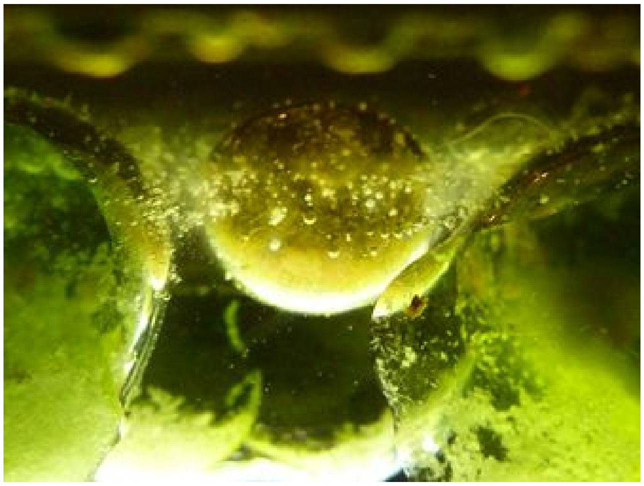

Figure 4: [Photograph Rachel Armstrong, Southern University of Denmark, April 2011.] Modified Bütschli droplets produce complex structures in the presence of mineral solutions.

Figure 5: [Photograph Rachel Armstrong, Natural History Museum, Vienna, April 2011.] Modified Bütschli droplets exhibit Turing band pattern formation.

the formation of insoluble, magnetic 'magnetite' crystals by adding iron II and iron III salts (Berger et al., 1999). These design-led experiments produce sculptural inclusion bodies that can be used to indicate change over time in systems and have been used in installation work such as The Hylozoic Ground (figure 6).

External environment modification

Changing the external chemical conditions of the medium can also alter the behaviour of the Bütschli system based on physical and chemical changes, such as surface tension and chemotaxis (Toyota et al., 2009). For example, adding ethanol, or 'alcohol' to the olive oil field, produces a rather a dramatic effect characterised by the population-scale, sudden movement of the Bütschli droplets towards the alcohol source (figure 7). This may be explained by changes in surface tension that promote movement of the droplet dynamics, but also by reducing the viscosity of the olive oil (Armstrong, 2015).

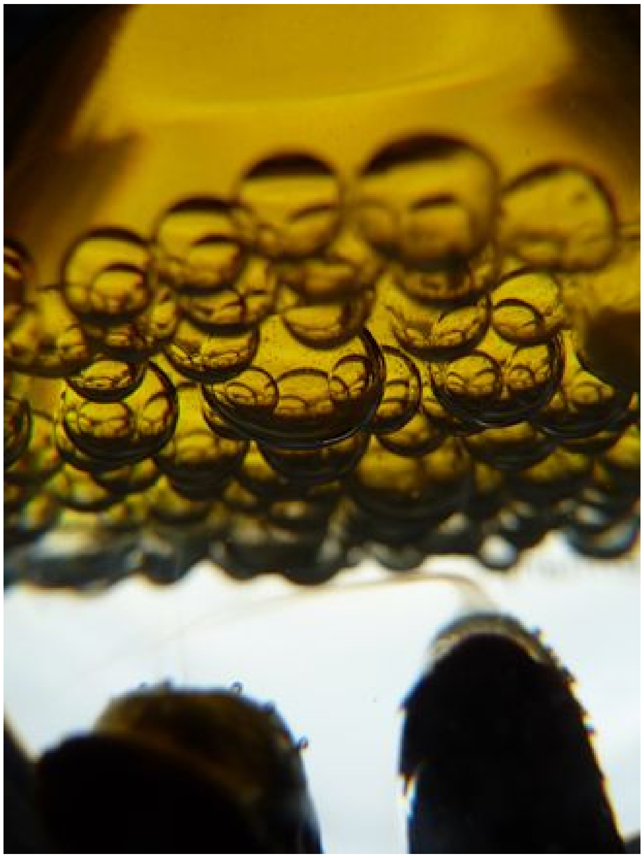

Figure 6: [Photograph Rachel Armstrong, Southern University of Denmark, Odense, June 2009.] Modified Bütschli droplets produce magnetite bodies that move through the droplet and produce stalagmite-like osmotic structures when they come in contact with iron II and iron III salts in a ratio of 1:2.

Population scale interactions

Perhaps surprisingly, dissipative systems are remarkably predictable, although they produce a spectrum of outcomes that operate within 'limits' of possibility, which are imposed by the properties of the system and its contexts (figure 8). Dissipative structures are highly resilient and able to transform themselves – structurally and morphologically – according to changes in their interior and exterior environment. They can also form reversible groupings that generate the life-like behaviours, which account for their flexibility, robust-

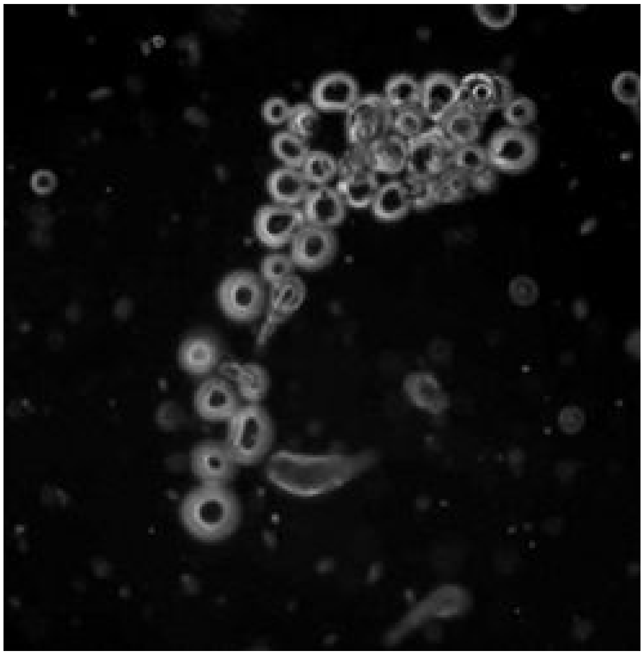

Figure 7: [Movie still Rachel Armstrong, Southern University of Denmark, Odense, June 2009.] Bütschli droplets respond to the presence of ethanol by clustering around the site of its addition to the olive oil medium.

ness and environmental sensitivity. However, populations of dissipative structures may periodically behave unpredictably when a tipping point is reached and give rise to novel, emergent, complex events that cannot be deduced from their characteristic behaviours (figure 9). New ways of accurately describing what is happening during striking phase changes are needed to more fully describe the continuous nature of change and its material complexity. Currently phase changes are described according to a set of recognisable meta-patterns that are documented over a series of time intervals. The relational aspects of tipping points therefore escape comprehensive description and analysis because of the way the system is observed during these events.

Elemental infrastructures

Enabling flow

Life-promoting elemental media are essential in facilitating the dynamic exchanges that allow dissipative structures to persist and evade the decay towards a disordered state, namely: air, heat, water and earth. Such infrastructures help optimise the conditions of maximalism and dissipative adaptation, whereby replenishing environmental media assists in producing complexity and dissipating heat in a self-organising system. Such infrastructures that form the basis of our water and nutrient cycles are likely to be critical in making the transition from inert materials towards lifelike

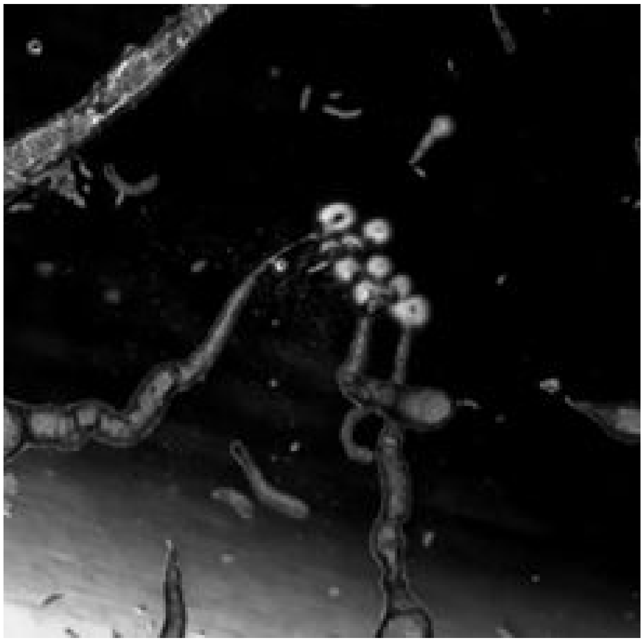

Figure 8: [Movie still Rachel Armstrong, Southern University of Denmark, Odense, June 2009.] Spontaneous assemblage of Bütschli droplets producing osmotic structures.

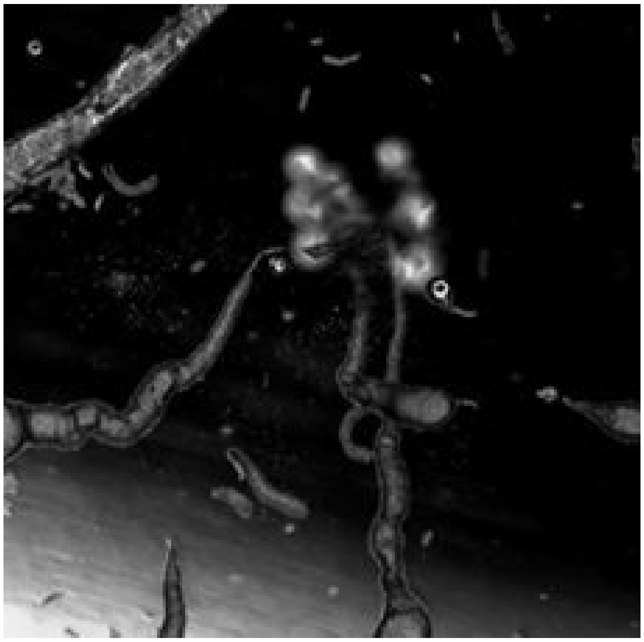

Figure 9: [Movie still Rachel Armstrong, Southern University of Denmark, Odense, June 2009.] Spontaneous phase change in morphology and behaviour in an assemblage of dynamic droplets that reach an unknown chemical ‘tipping point’ in the system.

systems.

Hylozoic Ground

The dissipative structures designed for Philip Beesley's Hylozoic Ground installation at the 2010 Venice Architecture Biennale were supported by a primitive infrastructure of elemental media. This jungle-like, room-sized, cybernetic, interactive mechanical matrix detected gallery visitors through an array of sensors that were coupled to effectors through a primitive neutral network. On activation the system shivered and raised friendly rubbery fronds of spikes as a somewhat disconcerting but entirely harmless greeting (figure 10).

Modified Bütschli droplets were installed as the dissipative system of choice, which could persist for the full 3-month duration of this exhibit where sustenance was provided through an arrangement of flasks containing Venice lagoon water that was open to the gallery atmosphere. Here, Bütschli droplets were entangled with the cybernetic system and its environmental interactions by responding to the presence of carbon dioxide through the production of tiny, brightly coloured structures about the size of a little fingernail that grew through the support provided by the liquid media in the flasks. Walking through this installation might be likened to exploring inside a giant nose – where the plastic fronds act as sinus hairs and the 'golden apple-like' flasks are 'smart' snot glands that can 'smell and taste' the presence of carbon dioxide. The Hylozoic Ground flasks were open to the air, and so enabled the on-going exchange of carbon dioxide across the air/water interface and increased the synthetic capacity of the modified Bütschli droplets.

Future Venice

Natural computing techniques are explored at the urban scale in the Future Venice project. The foundations of the city were bestowed with lifelike qualities by equipping them with a system of dissipative structures capable of many acts of synthesis through their interactions with the lagoon water. In turn, these designed metabolic networks enable the urban fabric to literally fight back against the damaging effects of natural elements in a struggle for survival – and therefore secure its longevity.

The dissipative system took the form of a series of dynamic droplets with a range of different chemical programs. Their metabolic interactions were demonstrated in the laboratory and experimentally designed to 'converse' with the lagoon environment. The combined interactions of these programmable droplets was to produce an accretion technology that is mediated at the interface between the lagoon water and the dynamic droplets. The watery infrastructure of the city provides the specially engineered droplets with an abundant flow of nutrients such as, dissolved carbon dioxide and minerals, whereby the collective action of the droplets forms an artificial garden reef underneath the city's foundations. This gradually creates a solid structure that spreads

Figure 10: [Photograph Rachel Armstrong, Canadian pavilion, Architecture Biennale, Venice, August 2010.] The Hylozoic Ground installation is a cybernetic matrix that integrates a range of different dynamic chemistries to aesthetically and functionally complement the dynamic processes that inform architect Philip Beesley's installation. Here, chemical organs containing modified Bütschli droplets are open to the air and produce solid carbonate microsculptures in response to the presence of carbon dioxide.

Figure 11: [Photograph Rachel Armstrong, Canalside Venice, August 2010.] Stromatolite-like formations in the Venetian canals are shaped over time to produce mineralised materials.

Venice's point load over a much broader base. Consequently Venice is prevented from sinking so quickly into the soft mud that it has been founded on (figure 11). A natural version of this accretion process is observed around the lagoon side and the canals, which is orchestrated by the native marine wildlife. Potentially, dynamic droplets could work alongside these organisms to co-construct an architecture that is mutually beneficial to the marine ecology and the city.

Importantly, should the environmental conditions change and the lagoon dries out – say for example, Pietro Tiatini and his colleagues succeed in anthropogenically lifting the city by pumping seawater into its deflated aquifers (Teatini et al., 2011), or if when the MOSES gates are raised in 2014 the native ecology reaches a catastrophic tipping point (Water-technology.net, 2015) – then the natural computer, which consists of the Venice waterways and the smart droplets, can follow a different program and re-appropriate its actions. Specifically, as the waters subside droplets coat the woodpiles in a downwards direction with a protective layer of 'biocrete' that stops them rotting when they are exposed to the air – instead of spreading outwards to form a reef.

Potentially natural computing processes could be applied to the whole bioregion of Venice. Facilitated by flowing water, the right kinds of metabolisms and spatial programs could give rise to tactics that generate, new relationships between natural and artificial agents. These may become the bedrock for forging life-promoting, synthetic ecologies. In this context natural computing enables a constant flux between fabric, space, structure and location. The outputs of the system do not imitate Nature but work as an alternative kind of life-promoting system – using a common chemical language based in physics and chemistry that is shared with the natural world. The idea of self-assembly in the production of materials and life-like architectures creates a potential commercialisable portfolio of solutions to deal with rising sea levels in coastal areas, bio-compatible materials, architectures that can deal with wet conditions and self-repairing systems. None of these possibilities have been formally productised but are informing further experimental research.

Yet, the design-led experiments that inform Future Venice do not propose to be a complete solution for the city's precarious future – or indeed erase our legacy of environmental woes. They do not attempt to 'solve' the inevitable changes that accompany a lively environment but open up the possibility of new approaches in addressing complex environmental events. Such dynamic practices generate new possibilities for metropolitan environments beyond the city of Venice. When adequately perfused by elemental infrastructures, they enable designers and engineers to regard urban landscapes as sites for pulsating, vibrating, transforming, flowing materials that may produce new kinds of experiences and spaces for innovation and inhabitation.

Building material complexity

To sustain the liveliness of an environment, a network needs to be prevented from reaching equilibrium. Technologies such as, continuous flow systems facilitate the persistence of dissipative structures (Graziani et al., 1976), where the increased complexity provided by these enriched environments also attenuates the participating bodies from reaching thermodynamic equilibrium. The infrastructural design of a dissipative system is therefore as important as the choice of oscillator system within it.

While dynamic droplets are supported in a free and open elemental medium like water, gels provide a matrix where water can move through structure. Gels provide the substrates for experimental systems that help investigate the kind of infrastructural support to facilitate the free flow of water, matter and air through the space. While their structure is nowhere near as complex as a cell milieu, or terrestrial soils, they create a set of conditions, such as diffusion and gradient formation, which provide an open system for experimenting on persistent dissipative structures.

Of particular interest in this context, Liesegang rings can demonstrate the generation of complexity within gels – a phenomenon that was discovered in the 19th century in developing photographic plate technology (Liesegang, 1896). The system is produced by soluble salts introduced into 'activated' (alkaline) gels that move sequentially as soluble and insoluble complexes through the matrix under the influence of gravity. The complex chemistries produced through activated gel systems were visualised in the Hylozoic Ground installation through Liesegang ring plates. These specially constructed narrow containers marked the passage of chemical time by the coupling and clustering of their dynamic chemical interactions.

Gel-based infrastructures facilitate natural computing strategies to generate increasingly complex interfaces that, through a range of differential physical and chemical phenomena, are rolled and folded in time, like embryonic plates. They demonstrate the multi dimensionality – or spatial nature – of natural computing that is also shaped through its historical events and contexts. These design-led experiments highlight the need for further research and development in the understanding of the development of dynamic elemental media and how these may be structured within a range of contexts – such as in under-imagined spaces within buildings like facades, cavity walls and underfloors – in which lifelike technologies and events may be desired e.g. in the production of chemical heating systems through composting processes.

'Artificial' soils as a potential origins of life sciences research discipline

While gels may prolong the actions of natural computing for days, or even months, persistent complex exchanges within the structure of matter are most successfully embodied in the story of soil, which enabled life to make the transition from

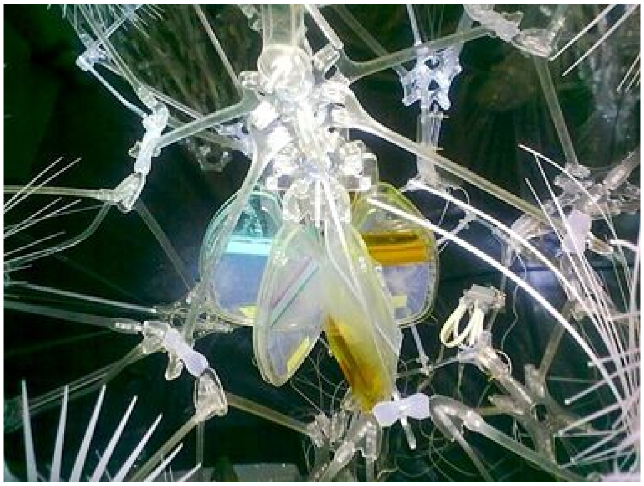

Figure 12: [Photograph, Rachel Armstrong, Hylozoic Ground installation, Venice Architecture Biennale 2010.] Clusters of vertically mounted Liesegang ring plates were introduced as a time-based chemical system in the Hylozoic Ground matrix, like the bark of a tree.

a watery, to a land based environment. The Earth was not 'born' with soil but has acquired its living web of relationships over the millennia (Logan, 2007), which form living bodies on a geological scale. Soils are integrating infrastructures on an architectural scale and attractors of terrestrial life. They enable materials to be transformed in the free flow of elemental systems through their bodies, such as air, water, heat and matter. This innate complexity may have been key to biogenesis, which has been recently suggested in work with clays that act as biotic catalysts, such as montmorillonite (Hanczyc et al., 2003). Indeed, William Bryant Logan proposes 'the clay code' is "*more complex than either the genetic code or human language*" (Logan, 2007, p127).

Yet soils are more than just their chemical ingredients, they are a highly structured spatial system and processing platform that promotes lifelike and living systems. They possess a reticular network of channels and spaces through which elemental systems can readily flow. The journey and topology of these labyrinthine spaces plays an important role in provoking complexity in the matter that passes through – and even becomes assimilated by – the soil body. This means that within a soil structure, matter is processed differentially and substrates are subject to different conditions depending on their position within the soil matrix. While we take many of these operations for granted in a terrestrial context, their complex spatial and chemical relationships are essential for generating the sustained metabolic networks that form our ecologies. Notably, the matter that passes into a soil system also becomes an integral part of the soil body – not just structurally but also physiologically.

The active spatial programming of soils through physiological processes was documented by Charles Darwin, who observed that earthworms were responsible for the movement of large stones into the earth. In this context, worms acted as a kind of local 3D printer system. They obtained the printing material by removing dirt from underneath the rocks and then re-depositing it on to the surface as casts. The stones therefore sunk into the ground faster than gravity alone (Darwin, 2007).

Conjecturally, soils may be considered as a production platform for dissipative structures, elemental matrices and natural computing tactics, which collectively contribute to a process of dynamic complexification. The strategic manipulation of these relationships may increase the probable emergence of lifelike systems – but also sustain and propagate them once they have arisen. Indeed, the production of 'artificial' soils may be regarded as an appropriate area for scientific research in the origins of life portfolio – and may provide new insights into generating environments in which the persistence of lifelike events becomes increasingly likely.

Conclusion

While origins of life sciences have generally been regarded as blue-sky sciences, the insights developed in the late 20th century have enabled designers to work with lifelike properties and non-equilibrium material systems. The origins of life sciences may help us deal with more complex and dynamic physical realm, where the process of discovery, language generations and cultural contingency can greatly enrich developing practices. Together, design and the origins of life sciences may generate new technological platforms that can produce a new portfolio of solutions – where 'life' itself may not be regarded as the only end point of research but is part of a whole new range of technical systems that increase environmental liveliness in an ecological era.

References

Adamatzky, A., Bull, L., Costello, B. D. L., Stepney, S., and Teuscher, C., editors (2007). *Unconventional Computing 2007, Bristol, UK, July 2007*. Luniver Press.

Adamatzky, A., De Lacy Costello, B., and Asai, T. (2005). *Reaction-Diffusion computers*. Elsevier Science.

Armstrong, R. (2015). *Vibrant Architecture: Material Realm as a Codesigner of Living Spaces*. De Gruyter.

Armstrong, R. and Hanczyc, M. (2013). Bütschli dynamic droplet system. *Artificial Life Journal*, 19(3-4):331–346.

Berger, P., Adelman, N. B., Beckman, K. J., Campbell, D. J., Ellis, A. B., and Lisensky, G. C. (1999). Preparation and properties of an aqueous ferrofluid. *Journal of Chemical Education*, 76:943–948.

Darwin, C. (2007). *The Formation of Vegetable Mould Through the Action of Worms (reprint)*. The Echo Library.

Graziani, K. R., Hudson, J. L., and Schmitz, R. A. (1976). The Belousov-Zhabotinskii reaction in a continuous flow reactor. *The Chemical Engineering Journal*, 12(1):9–21.

Hanczyc, M. M., Fujikawa, S. M., and Szostak, J. W. (2003). Experimental models of primitive cellular compartments: encapsulation, growth and division. *Science*, 302:618–622.

Hight, C. (2007). *Architectural principles in the age of cybernetics*. Routledge.

Ikegami, T. and Hanczyc, M. (2009). Search for a first cell under the maximalism design principle. *Technoetic Arts*, 7(2):153–164.

Latham, W. (1988). Conquest of form: Computer art by william latham. Exhibition at Arnolfini Gallery, Bristol.

Lee, M. (2011). *Oceanic Ontology and Problematic Thought*. NOOK Book/Barnes and Noble.

Liesegang, R. E. (1896). Ueber einige Eigenschaften von Gallerten. *Naturwissenschaftliche Wochenschrift*, 11(30):353–362.

Logan, W. B. (2007). *Dirt: The Ecstatic Skin of the Earth*. W. W. Norton & Company.

Pfeifer, R. and Iida, F. (2005). Morphological computation: Connecting body, brain and environment. *Japanese Scientific Monthly*, 58(2):48–54.

Teatini, P., Castelletto, N., Ferronato, M., Gambolati, G., and Tosi, L. (2011). A new hydrogeologic model to predict anthropogenic uplift of Venice. *Water Resources Research*, 47(12):W12507.

Toyota, T., Maru, N., Hanczyc, M. M., Ikegami, T., and Sugawara, T. (2009). Self-propelled oil droplets consuming “fuel” surfactant. *Journal of the American Chemical Society*, 131(14):5012–5013.

Turing, A. M. (1952). The chemical basis of morphogenesis. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 237(641):37–72.

Wakefield, J. (2013). TED 2013: 4d printed object ‘make themselves’. BBC news technology. http://www.bbc.co.uk/news/technology-21614176 [Accessed 1 March 2015].

Wolchover, N. (2014). A new physics theory of life. *Quanta*. https://www.quantamagazine.org/20140122-a-new-physics-theory-of-life/. [Accessed 10 February 2015].