Potent Matter: The Dynamic Chemistries of Hylozoic Ground

Rachel Armstrong

> And growing still in stature, the huge Cliff
> Rose up between me and the stars, and still,
> With measur'd motion, like a living thing,
> Strode after me...
>
> William Wordsworth
> The Prelude, Book 1: Childhood and School-time

Architecture may be considered as the ontology, epistemology and pedagogy of the production of space. Its territory extends way beyond the construction of buildings, the shaping of social and private spaces, acts as a screen for our desires, a stage for wars, provides context to our new technologies, becomes a site where myriads of material relationships are forged, a sanctuary for secrets, a theatre for our triumphs and may constrain, or nurture us. Yet in the late 20th century architecture has become equated with the construction of monuments to industrialization. The colossal phallic Burj Khalifa tower, Qatar's vulval 2022 World Cup Stadium design and the futuristic Infinite Loop Apple Headquarters, speak of artifice having conquered the natural world in imposing its will upon matter by realizing its striking mathematically-derived forms upon native land-scapes. Through industrial construction technologies, oneiric structures can now be conjured by subduing matter to our geometric command, as it if was no more trivial than writing an algorithm for a virtual reality program.

IN DEFENSE OF MATTER

Modern paradigms that underpin industrial production processes are a *"revolution operating on matter"*[1], which propose that it can be reduced to bundles of brute substances that are merely fit to be consumed by machines. Yet, according to Maurice Merleau-Ponty, the 'flesh of the world' is composed of more than the naïve summation of fundamental qualities but through an

1 Brown, S.D. 2002. Michel Serres: Science, translation and the logic of the parasite' *Theory, Culture & Society*, 19(3), pp.1-27.

facing page

2 Radiant Soil, Paris, 2013.

awakening in our bodies[3]. Indeed, the effects of many contributing agencies produce the material realm. Yet, while a whole spectrum of philosophical perspectives speculate on the nature of matter, each perspective becomes a simplification or abstraction of what matter 'actually' is. For example, the material realm is more than the consequences of Bruno Latour's interacting actants[4], or Henri Bergson's "self-existing images" [5] and nor is it simply the consequence of language. Indeed, no single, reduced view of the material realm can provide a complete view of its character. Rather our experience of matter is shaped by deeply entangled relationships and emergent properties that result from complex interactions, which Karen Barad and Donna Haraway propose are diffractions of matter that continually interfere with each other to produce unique, emergent patterns[6] that may underpin material creativity[7]. Indeed, the true complexity of the material realm can only ever be partially observed within different existence spheres, such as language, phenomenology and realism.

So, in our Heraclitean reality – a world in continual flux – matter is a lively and complex force to be reckoned with. A 21st century theory of matter requires a new conceptual operating system for matter that is based on an appreciation of the properties of non-equilibrium. My research explores how assemblage[8] theory may provide a dynamic, complex understanding of the material realm without presuming that all effects are completely understood. The term assemblage is currently a philosophical concept that refers to platforms where specific groupings of actants form heterogeneous bodies that produce material encounters and even hypothetical entities that are porous, transitional and mutable. It is likely that the entire range of experiences with assemblages have not been discovered, or even invented yet, perhaps in a similar manner to how Jean Marie-Lehn's supra-molecular chemistry[9] has enabled us to synthetize new substances for the first time in the history of the universe.

Yet, to truly begin to apprehend the nature of 21st century matter, it requires a direct conversation with the material realm so that it may reveal further findings about its contrary character to inform our observations of it through experimental data, cultural theory and thought experiment. My research has therefore uniquely operationalized the concept of assemblages in a material context, so that it may be explored and interrogated as a real model of a philosophical proposition and to engage the voice of the material realm through the language of chemistry so that it may inform the experiments, potentially in surprising ways.

3 Merleau-Ponty, M. 1993. Eye and mind. In the Merleau-Pony aesthetics reader, Philosophy and painting, ed. G.A. Johnson. Evanston: Northwestern University Press, pp. 121-149.

4 Latour, B. 2005. *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

5 Bergson, H. 2004. Matter and memory, Mineola, New York: *Dover philosophical classics*.

6 Barad, K. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press.

7 Prigogine, I. 1997. *The End of Certainty: Time, Chaos and the New Laws of Nature.* 1st edition. New York: The Free Press.

8 Deleuze, G. and Guattari, F. 1979. *Thousand Plateaus: Capitalism and schizophrenia* (Athlone Contemporary European Thinkers). London: The Athlone Press.

9 Lehn, J.M. 1988. Perspectives in Supramolecular Chemistry-From Molecular Recognition towards Molecular Information Processing and Self-Organization. *Angewandte Chemie International Edition*, 27 (11): 89–121.

Indeed, 21st century matter possesses a subversive character that is lively and partly co-authors our experience of reality[10,11]. Yet, we lack the conceptual toolset to see, describe or properly handle the full spectrum of its creative potential. 21st century design practices therefore require new approaches since now we have access to apparatus through which can manipulate quantum phenomena. Therefore we may now be more directly involved in the re-ordering, transformation, or annihilation of matter in ways that were previously unattainable. Even without access to specific apparatus, 21st century objects can also negotiate quantum field theory, where they can be suddenly brought into being and extinguished, navigate wormholes, respond to dark matter and exhibit ‘quantum tunneling’. In other words, we can now appreciate that matter may act in ways that seemingly defy intuition, or even Newton’s classical laws of material conservation. Indeed, a 21st century theory of matter completely contradicts notions of homogeneous atomism whereby every substance is made of correctly ordered fundamental particles. Yet modern physics has demonstrated the existence of a diverse range of primitive material fragments that exist so briefly they have to be ‘made’ in giant technologies such as the Large Hadron Collider (LHC). This structure - the largest Swiss watch ever made - accelerates plasma beams to near the speed of light, and then smashes them into each other to produce a heterogeneous range of primitive particles. In this rarefied context, we are seeing matter in evolution, which does not directly relate to an everyday philosophy of objects but nonetheless highlights the strange nature of matter and the encounters that shape our understanding of it.

Indeed, Gaston Bachelard’s heurestical notion proposes that there is no simple substance - only complex objects, which can be built by theories and experiments that are iteratively improved upon[12]. Yet, 21st century materiality appreciates that objects are more than complex entities but also highly dynamic structures. Indeed, at the subatomic level, all substances are vibrating and behave discontinuously across scales. It is not clear, for example, why gold is a red, active substance in colloidal form at the nanoscale and a largely inert material with a characteristic hue at the macroscale. So, when matter is dynamic, it behaves according to the laws of non-equilibrium systems. While some objects are encountered at relative equilibrium at the macroscale, such as a table, London Bridge, or the metallic shell of an aeroplane, at the quantum scale they will nonetheless behave as far from equilibrium systems, although this will not be directly observed.

10 Barad, K. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning.* Durham: Duke University Press.

11 Bennett, J. 2010. *Vibrant matter: A political ecology of things.* Durham: Duke University Press.

12 Bachelard, G. 1994. *The poetics of space: The classic look at how we experience intimate places.* Beacon Press: Boston.

A 21st century phenomenology requires engagement with the incompletely characterized, innate potency and strangeness of the material realm. This emanates from multiplicities and existential paradoxes, such as in quantum physics where matter appears to behave as both particle and wave[13]. These observations are entangled with notions of complexification that raise the possibility of continual convergence between different modalities despite modern insistence that aspects of reality are discrete. Indeed, a 21st century philosophy of objects appreciates that the physical world is composed of chimaeras and inconstant substances. They exhibit recognizable qualities that are not absolutes, but they are sufficiently persistent for them to be identifiable. However, with time these qualities may change. These potential permutations confer the material realm with its formidable presence and straddle the grotesque and sublime. Indeed, a 21st century theory of objects is socially relevant and empowers them with political agency so they may claim (co)authorship in the production of our living spaces by producing effects that impact on human activities, such as the noxious chemicals secreted by decomposing garbage tips or sudden power outages of national electricity grid systems[14]. We may also view this empowerment as part of our own agency in the world so that we, as material expressions, may also inhabit a physical realm that it is not reduced, abstracted or disconnected. Rather, we may understand that our own physical being in the world, of being a body, may influence our experience of reality in ways that surprise us, such as in recovering from a serious illness, or through record-breaking achievements and acts of spontaneous creativity.

Our most potent encounters with 21st century materiality are experienced as massive, spontaneous material shifts that are dictating the context in which architecture exists. They are understood as global phenomena, such as climate change, which may be understood as observations in environmental conditions that can be attributed to specific causes, such as climbing partial pressures of carbon dioxide, greater than average rainfall, reductions in biodiversity, the march northwards of tropical diseases, or apparent shifts in the earth's magnetic poles. However, these material expressions are also associated with a cultural phenomena such as Swangeddon, where swans replaced people in the streets of Worcester when the banks of the River Severn flooded on Christmas Eve, 2013[15]. With an awareness that climate change is at least partly precipitated by anthropogenic causes, these extreme events are also no longer entirely naturalized[16], or meet our aesthetic expectations of the natural world[17].

13 Barad, K. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press.

14 Bennett, J. 2010. *Vibrant matter: A political ecology of things.* Durham: Duke University Press.

15 Edmonds, L. 2013. Seven swans a-swimming! Inquisitive birds make the most of river's burst banks to go exploring. Mail Online. [online] Available at: *http://www.dailymail.co.uk/news/article-2528924/Severn-swans-swimming-Inquisitive-birds-make-rivers-burst-banks-exploring.html*. [Accessed 15 March 2014].

16 Van Mensvoort, K. and Grievink, H.J. 2012. *Next Nature: Nature Changes Along with Us*. Barcelona: Actar.

17 Morton, T. 2007. *Ecology Without Nature: Rethinking Environmental Aesthetics*. Cambridge: Harvard University Press.

To fully access this rich material potential a new toolset for working with dynamic matter is needed. My research aimed to operationalize the philosophical concepts underpinning the notion of a lively, empowered material realm at far from equilibrium states by identifying dissipative structures as an experimental model through which proposals could be practically demonstrated and tested[18]. My work also proposed to engage the voice of the material realm through the language of chemistry, so that it could inform experimental outcomes. Dissipative structures proved to be an ideal experimental model to explore dynamic materials in an architectural context, since they straddle the conceptual realms of object and process-oriented theories. They are simultaneously objects that possess structure and also embody process through a simple 'metabolism' [19] that takes energy from outside the system and transforms it into a range of lively material phenomena, whose integrity is maintained by a continual flow of atoms and energy. Dissipative structures, also known as systems, exhibit lifelike properties that can be demonstrated and tested in architectural design contexts to produce tools[20] and technical objects[21]. Specifically, dissipative structures can deal with architectural programs by applying Natural Computing techniques[22] as outlined by Bernard Tschumi, which entangle 'space, event and movement' [23]. They also possess an architectural quality according to Mark Morris' notion of *"miniature thinking"*, where the collective organization of agents with qualities unique to their scale can link the small and full-scaled worlds in an emergent, dynamic temporal relationship that invokes the fantastic and uncanny through scalar fantasy and alchemical lore[24]. From an experimental perspective, exploring the surprising properties of objects is more feasible when they are encountered at the human scale and are far from equilibrium. Using dissipative structures as a technological platform that is operationalized by assemblage theory and instrumentalized by natural computing, it is possible to work in new ways with 21st century matter to produce complex expressions of materiality that are encountered as rich ecologies, rather than the reduced formalism of machines which typifies the production of contemporary architecture[25]. Indeed, designing, building and operationalizing the *Hylozoic Ground* chemistries over the last few years has provided insights that gesture towards a 21st century theory of matter.

BACKGROUND TO THE HYLOZOIC GROUND CHEMISTRIES

When I first started working on the chemical designs for the *Hylozoic Ground* series using a range of dissipative structures, such as 'protocells', Traube cells

18 Prigogine, I. 1997. *The End of Certainty: Time, Chaos and the New Laws of Nature*. 1st edition. New York: The Free Press.

19 I am using the term 'metabolism' in this case to refer to a simple chemical reaction that prolongs the dynamic state of a lifelike material system by keeping it away from reaching effective thermodynamic equilibrium (Schrödinger, 1944), rather than invoking the biological concept of a complex network of biochemical interactions that maintain the processes underpinning life.

20 Heidegger, M. 1993. The Question Concerning Technology. In William Lovitt and David Farrell Krell eds. Martin Heidegger, *Basic Writings. Revised and expanded edition*, pp. 287-311.

21 Massumi, B. 2012. 'Technical mentality' revisited: Brian Massumi on Gilbert Simondon. In: A. De Boever, A. Murray, J. Roffe and A. Woodward eds. Gilbert Simondon: *Being and technology.* Edinburgh: Edinburgh University Press, pp. 19-36.

22 Natural computing is a set of unconventional computing practices that engage with the computational properties of the material realm by applying spatial programs to shape events, and is discussed in more depth in a separate section in this essay.

Denning P. J. 2007. Computing is a natural science. *Communications of the ACM*, 50(7), pp. 13-18.

23 Tschumi, B. 2012. Architecture concepts: Red is not a colour. *Rizzoli international publications*.

24 Morris, M. 2011. Dream a little dream. *Architectural Design*, 81(2), pp.44-49.

25 Le Corbusier. C.E. 2007. *Toward an architecture.* Los Angeles: Getty Research Institute.

and various chemical organs, they were conceived and designed as functional objects that had the potential to couple with an existing system through process-enabled encounters, or simple metabolisms. While the objects themselves possessed unconventional properties - in that they were lively and were compelled to connect with other bodies within specific windows of opportunity - they were nonetheless produced through what is best described as an 'artisan chemical practice.' A range of different chemistries was developed for the *Hylozoic Ground* installation, each with a unique character. In 1892 Otto Bütschli first described simple oil in water mixtures that are powered by a saponification process and take the form of programmable lifelike droplets[26]. When these so-called Bütschli droplets are observed with the naked eye, they show striking lifelike qualities. For example, they are able to move around their environments, sense their surroundings, interact with each other and synthetize solid matter. Another species of active chemistries based on banding chemical structures described by Raphael Liesegang, called Liesegang Ring Plates, were produced, taking the form of activated gels through which partially solution coloured salts moved through the matrix under the influence of gravity that marked time as chemical clocks, through the diffusion and precipitation of reactive chemical complexes. Another dynamic chemical species, originally described by Moritz Traube in 1867, known as Traube cells, underwent a striking transformation of colour, volume and shape from blue diamond shaped crystals into swelling brown seaweed-like membranous fronds. Each population of dynamic chemistries was constructed using a hand held pipette and mounted carefully within special housing. For example, the Bütschli droplets were suspended at an oil interface for maximum visibility from underneath in hand-blown spherical flasks that acted as lenses through which the droplet populations were magnified and bathed in a radiant halo. The ambition was to develop systems with weak technological functions that could be coupled with the cybernetic network of interacting bodies. The outputs were initially imagined as similar to the organic vinegar and lemon batteries that Beesley had already been working with in the *Sargasso* installation; a geotextile meshwork created with Mette Ramsgarde Thompsen for the COP15 exhibition at the Royal Danish Academy in 2009.

Indeed, the initial pedagogy of the dynamic chemistries was therefore centred on an investigation of their epistemologies, typologies and functions. This included applied encounters such as troubleshooting for missing key ingredients where ingredients that could be used in a domestic setting, such as glycerine

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

and food colouring, were substituted into the preparation and created a different portfolio of outcomes[27]. As the *Hylozoic Series* evolved through many sites and configurations, the nature of production of the dynamic chemistries also changed. Rather than being produced by artisans, they were translated into robust recipes that could be repeatedly executed by non-scientific collaborators. Gradually, the systems of production of these procedures also changed and could take place through an increasingly remote and distributed process that depended on the orchestrated actions of many dedicated contributors. With the international proliferation of different organ species within the various manifestations of the *Hylozoic Series* and also in discrete installations in group shows, including the 'kitchen protocells' made for the 'On Architecture' group show in Belgrade[28], the dynamic chemistries have begun to play a very different role in design philosophy. They have taken on a greater status than merely connectable 'objects', or soft technologies, but provide a tool for structural coupling between specific geographies of objects. They therefore provide access to a lively, interconnected material realm in which we are all immersed. This is not simply an attitude or an intellectual stance on the nature of reality, but a physical engagement with a set of principles that dynamic chemistries can help reveal, and actively interrogate. This suggests that at far from equilibrium states, chemistries may help us investigate aspects of the material realm in ways that mechanisms cannot.

CHEMISTRY AS TECHNOLOGY

Simondon proposes 'technical objects' fall into two types: Cartesian and cybernetic[29]. I propose that chemical technologies constitute a new category, or technical ordering, and are not simply soft machines (complete solutions) or cybernetic systems (adaptive) as they can transform their materiality. However, chemical technologies are not detached technologies but may horizontally couple with mechanical or cybernetic assemblages. Dynamic chemistries possess some of the properties of living systems and therefore, like biotechnologies, may invent unexpected outcomes in the course of their becoming or discover new operations to achieve these goals. Even in the most conventional sense dynamic chemistries are not simply 'objects'. In physical terms they are 'dissipative structures', which are highly ordered material systems that are produced when matter is at far from equilibrium[30]. Dynamic chemistries are produced by self-assembly within chemical networks like the Bütschli system[31] when one group of substances, such as olive oil, is added to another, such as a strong alkaline solution.

27 Modifications to the Bütschli system using domestic ingredients led to a separate practice of 'kitchen protocells' by constructing a field of interaction based on the dynamic properties of water, rather than on the saponification reaction that underpins the original preparation. An interface for the exchange of water was created by layering olive oil over glycerine and then adding food colourant to the system. The droplets temporarily rested at the interface between the two chemical fields before collapsing as water was drawn from the food colourant by the hygroscopic properties of the glycerine, leaving visible trails of matter that could be read as a 3D painting.
Armstrong, R. 2014. *Vibrant architecture: How 'vibrant matter' may raise the status of the material world in architectural design practice and be recognized as a codesigner of our living spaces.* Unpublished PhD thesis. University College London.

28 On Architecture, 10 December 2013. Gallery of Science and Technology, Serbian Academy of Sciences and Arts, Belgrade. [online] Available at: *http://www.strand.rs/architecture/program.html.* [Accessed 18 January 2014].

29 Massumi, B. 2012. 'Technical mentality' revisited: Brian Massumi on Gilbert Simondon. In: A. De Boever, A. Murray, J. Roffe and A. Woodward eds. Gilbert Simondon: *Being and technology.* Edinburgh: Edinburgh University Press, pp. 19-36.

30 Prigogine, I. 1997. *The End of Certainty: Time, Chaos and the New Laws of Nature*. 1st edition. New York: The Free Press.

31 Bütschli, O. 1892. *Untersuchungen ueber microscopische Schaume und das Protoplasma,* Leipzig.

The chemical field spontaneously spreads out and breaks up into millimeter scale droplets that can move around their environment, sense it, produce microstructures and interact with each other. Owing to the strong forces that exist between these sets of substances, they are *a priori* empowered objects and do not depend on an external energy source to animate them like machines do, so their interactions directly articulate existing sets of relationships.

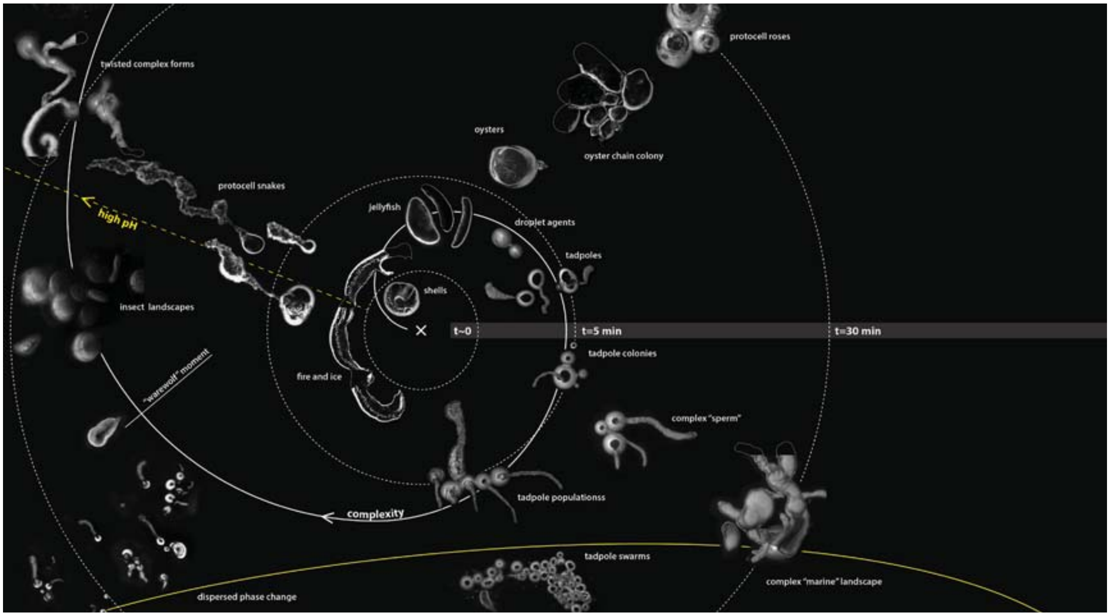
Dynamic droplets achieve their outcomes by inserting time and space into matter through spontaneous movement produced by the mass flow of molecules in the system, which evades the decay towards equilibrium. This is consistent with biological systems that are highly reticular and are spatially and temporally organized, such as the endoplasmic reticulum, which constitutes a site in which biochemical processes are spatially distributed throughout the body of the cell. Within this interior labyrinth, a host of metabolic processes are catalyzed and transformed to create a chain reaction of self-perpetuating chemical flow, where the output of one reaction becomes the beginning of another. In this way, living systems maintain their operational integrity as transformers since not all their chemical relationships are simultaneously active or in the same place and are therefore separated in time and space.

It is important to note that these exchanges are literal. They are not imagined, represented or translated in any way. They constitute a virtual field of possibilities that can evolve and resolve in different ways through matter. Yet because they are ultimately real, their actual outcomes can only embody one possibility from a range of possible material expressions. I mapped the field of potentiality of the Bütschli system by recording the structural and behavioural performance of over 300 Bütschli droplet experiments using a Nikon Eclipse TE2000-S inverted microscope with Photometrics Cascade II 512 camera and in-house software, using the outcomes to design a cartographic system based on oceanic ontologies[32], which was drawn by Simone Ferracina[33].

The diagram reflects the potential activity of Bütschli droplets on an oil field, which may be considered as a stage, or architectural site, in which the interactions between droplets are 'actors' -the architectural program. Interactions generate events and leave physical traces on an ever-changing stage that operates beyond abstractions and directly records the site details as a generative, dynamic system, which Matt Lee describes as an 'oceanic ontology' [34]. The site details are organized on the diagram within concentric circles, which represent an exponentially increasing series of time intervals, where novelty and

32 Lee, M. 2011. Oceanic ontology and problematic thought, NOOK Book/Barnes and Noble. [online] Available at: *http://www.barnesandnoble.com/w/oceanic-ontology-and-problematic-thought-matt-lee/1105805765*. [Accessed 19 April 2013].

34 Lee, M. 2011. Oceanic ontology and problematic thought, NOOK Book/Barnes and Noble. [online] Available at: *http://www.barnesandnoble.com/w/oceanic-ontology-and-problematic-thought-matt-lee/1105805765*. [Accessed 19 April 2013].



33 Protocell Topology diagram

event frequency rapidly decrease with time. Complexity within the system is represented as a tightly curled spiral around the origin of the reaction. This provides an instrument through which the relationships between the Bütschli forms and their progeny may be grouped according to design preferences. While it is useful to find modes of recognition to navigate oceanic ontologies such as the Bütschli system, their expressions are probabilistic, complex, dynamic and highly contextualized resisting traditional classification systems. Indeed, they are consistent with Latour's notion of 'post-epistemological' phenomena[35].

Dynamic chemistries therefore embody the transformation of an object, specifically a dissipative structure, within a silent network of material systems, which are conjured when assemblages are brought into proximity with each other. These bodies may be engaged in acts of design as a technology of assemblages that offers its own disclosures and methods of production. When these systems are deployed as spatial programs they bring forth events from a technological fabric that has been so naturalized it has receded into the background of our daily lives and is now completely invisible to us. This technology is, of course, Nature, or as Bruno Latour prefers, OOWWAAB (Out Of Which We Are All Born)[36].

35 Latour, B. 2013. Once out of nature: Natural religion as a pleonasm. Gifford lec ture series, University of Edinburgh. [online] Available at: *http://www.youtube.com/ watch?v=MC3E6vdQEzk*. [Accessed 7 July 2013].

36 Ibid.

The *Hylozoic Ground* dynamic chemistries offer an evolving experimental platform that visualizes and shapes the material connectivity, novelty and transformation that already take place within natural systems and couples them with artificial systems. Dynamic chemistries enable the manipulation of these very simple ecological networks through the hardware of dynamic chemical objects and software of metabolism. However, dynamic chemistries also enable the deliberate modification of these networks, and while the underlying metabolic systems are sufficiently robust to accommodate local disturbances, the redistribution of chemical flows within these networks may eventually produce new kinds of Nature - entangled material expression of culture, ecology and technology [37]. As these exchanges become naturalized, their visibility withdraws from design practice and creates a primordial material matrix that is bursting with creativity. Indeed, this murky process underpins the material complexification and diversity that shapes the proto-ecologies of evolutionary change. Yet Nature is not neutral and deeply contextualizes which specific life forms may persist within a system through a process of Natural Selection. Such survival pressures arise from an existential sea of deeply entangled, mutable, unspecified entities. As their operations are observed, the transitional objects become increasingly ambiguous as their boundaries are being continually formed and reformed by complex networks of entangled interactions and the cultural forms of editing that attribute meaning to these configurations[38, 39]. Where some persist, others transform and many wither.

While proto-ecologies may be regarded as open fields of unevenly distributed assemblages, boundaries are still forged between them. Peter Sloterdijk proposes that these spaces are patrolled by a kind of 'immunology' of space[40], where certain structures are allowed to flourish and others are actively destroyed to allow the continued existence and evolution of the established system. Yet in a nonhuman world, boundary interactions are not exclusive to the behaviour of populations like flocks of migrating birds, schools of dolphins, or dynamic droplet assemblages, but also exist as strong and weak forces between objects, including gravity, electromagnetism, and strong and weak nuclear forces. These produce a host of interactions, including attractions, repulsions, amplifications and extinctions, which may be observed at the interface of trembling dynamic droplets, migrating Liesegang ring bands or blooming Traube cell membranes. Matter has its own immunology and object-technics, whose rules of interaction are forged by molecular bonds and physical forces that arise from many different agencies, some of which are human but many of them are not. While

37 Van Mensvoort, K. and Grievink, H.J. 2012. *Next Nature: Nature Changes Along with Us*. Barcelona: Actar.

38 Barad, K. 2007. *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning*. Durham: Duke University Press.

39 Bennett, J. 2010. *Vibrant matter: A political ecology of things*. Durham: Duke University Press.

40 Sloterdijk, P and Hoban, W. 2011. Bubbles: Spheres I - Microspherology: *Spheres Volume I: Microspherology: 1* (Semiotext(e) / Foreign Agents). MIT Press: Cambridge.

from a phenomenological perspective objects appear to resist and exceed their interactions, the *Hylozoic Ground* chemistries demonstrate that object bodies constantly throb with interaction at interfaces, where assemblages overlap with and are infused by the medium in which they exist. In the *Hylozoic Ground* installation, the various assemblages were designed in ways to reveal their relentless material exchanges through striking phenomena, such as the production of brightly coloured carbonate shells in the presence of carbon dioxide.

METHODS OF NATURAL COMPUTING

Since it is possible to shape the interactions of dynamic chemistries to achieve design outcomes, they may be regarded as arising in the shadowy realm between the 'born and the made' [41]. They possess natural qualities, technological capabilities and also computational abilities. Indeed, natural computing may be thought of as the design choreography of space, event and movement through matter, where the notion of an alternative kind of computation and technological platform has far reaching effects from cultural and environmental perspectives. The main goal of this field is to develop programmable, lifelike systems using a spectrum of platforms to better understand and reflect the properties of complex phenomena, such as adaptation, learning, evolution, growth, development and robustness. I will aim to draw together some of these threads as an entanglement of speculative writing, real world laboratory experiments, philosophical discourses and descriptions of project work while raising the possibility of working directly with Nature itself as a technology.

41 Kelly, K. 2010. *What technology wants*. New York: Viking.

Modern computing harnesses the properties of a particular kind of technology that uses mathematical abstractions and mechanical systems to build models of the world. Today, digital computers are such an integral part of our lives that we are harvesting vast amounts of data as if, the World Economic Forum observes, it was *'the new oil'*[42]. Yet digital computing has limits. It is not materially embodied but a symbolic expression of mathematics, and while it has enabled us to reflect on the shape of our thoughts to degrees that were formerly inaccessible, it does not enable us to directly materialize them. Instead, it relies on physical transformers, such as 3D printers that work indirectly to abstract and reinterpret possible material outputs, re-transposing them into a range of possible forms.

42 World Economic Forum on Europe and Central Asia, 9 June 2011. Personal Data: The "New Oil" of the 21st century, *World Economic Forum*. [online] Available at: *http://www.weforum.org/sessions/summary/personal-data-new-oil-21st-century.*

Mathematician Francoise Chatelin observes that if digital computing becomes entrenched as the only computing platform available to us, then it extinguishes the philosophy of mathematics since we cannot evolve concepts including number theory, which has the potential to bring us new symbols that possess meaning that extends way over and above the binary significations of the digital realm. By keeping the relationship between the philosophy of mathematics and computing very much alive, we may be able to find ways of realising forms of computing that directly couple with natural systems[43].

Nevertheless, the digital realm does not inevitably stand apart from the natural world. Rocco and Bainbridge advocate the facilitated convergence of the digital realm with other media by using advanced technologies, such as nano-technology, biology, information and cognition. They propose that this NBIC singularity has the potential to create new production platforms with radical new benefits for humanity and the economy[44].

Natural computing offers a potential site for NBIC convergence by orchestrating the properties of matter and therefore inseparably entangles information and materiality so that hardware and software are tightly coupled. Currently, natural computing embraces broad, overlapping and multi-disciplinary practices, including digital modelling of biological systems, unconventional computing, synthetic biology, complexity chemistry and some aspects of robotics. Researchers include Martin Hanczyc at the Southern University of Denmark[45], Lee Cronin at the University of Glasgow[46], Klaus-Peter Zauner at the University of Southampton[47], Gabriel Villar at the University of Oxford[48], and Andy Adamatzky at the University of West England[49].

Owing to its embodiment and its parallel processing abilities, natural computing outputs embrace a different spectrum of possibilities to those of machines. Over the course of human development, we have used living things in a technological context and manipulated them accordingly, from guiding the metabolic activities of horses as transport systems, to harnessing the genetics of different laboratory workhorses that underpin the emerging science of synthetic biology such as yeast, *Escherichia Coli* and *Mycobacteria* genitalium.

But natural computing operates at a much lower level than biology. It does not require a centralized coding system like DNA but works through distributed methods. It is based in the common language of all natural systems, which are shaped by physics and chemistry. Natural computing's operating system is instructed by the actions of assemblages, which articulate a reality in continual flux and actively build networks without the need for an external energy source. However, although I have operationalized assemblages as dynamic chemical system for

43 Chatelin, F. 2012. *Qualitative Computing: A Computational Journey into Nonlinearity*. World Scientific Publishing Company: Singapore.

44 Roco, M.C. and Bainbridge, W.S. 2003. Converging Technologies for Improving Human Performance, Nanotechnology, Biotechnology, Information technology and Cognitive science. *NSF/DOC-sponsored report*. Dordrecht: Springer.

45 Hanczyc, M.M. Toyota, T. Ikegami, T. Packard, N.H. and Sugawara, T. 2007. Fatty acid chemistry at the oil-water interface: Self-propelled oil droplets. *Journal of the American Chemical Society*, 129(30), pp. 9386 – 9391.

46 Cronin, L. Krasnogor, N. Davis, B.G. Alexander, C. Robertson, N. Steinke, J.H.G. Schroeder, S.L.M. Khlobystov, A.N. Cooper, G. Gardner, P.M. Siepmann, P. Whitaker, B.J. and Marsh, D. 2006. The imitation game—a computational chemical approach to recognizing life. *Nature Biotechnology*, 24, pp. 1203-1206.

47 Palmer, J. 11 January 2010. Chemical computer that mimics neurons to be created. *BBC News*. Available at: *http://news.bbc.co.uk/1/hi/8452196.stm*

48 Villar, G. Graham, A.D. and Bayley, H. 2013. A tissue-like printed material. *Science*, 340(6128), pp. 48-52.

49 Adamatzky, A. Bull, L. De Lacy Costello, B. Stepney, S. and Teuscher, C. eds. 2007. *Unconventional computing.* Beckington, UK: Luniver Press.

the *Hylozoic Ground* as a demonstrator for a new kind of production platform that reversibly couples with a range of material systems, they are not formally recognized as a technology. Nevertheless, they are relevant to design and engineering practices since they offer the potential to construct spatial programs and realize them in different ways to machine-based programs.

The operating principles of machines and assemblages are compared in the following table:

	MACHINE	ASSEMBLAGE
COMPONENT	Object	Agent
ORDER	Series	Parallel
POWER STRUCTURE	Hierarchical system	Non-hierarchical
FUNCTIONAL SYSTEM	Machine	Assemblage
ENERGY	Extrinsic	Intrinsic and extrinsic - spontaneous operations may be prolonged with resource supply
CONTROL	Hard	Soft
PREDICTABILITY	Deterministic	Probabilistic
TRANSFORMATION	Binary - on/off	Variable states. generally conservative but may behave unpredictably and collapse or transform at tipping points

However, working with the assemblages that form the operating system of natural computing as a technological platform is challenging as they require new toolsets to operate, record and evaluate their impacts. They are very different to object-centered systems as they are sensitive to and forge connections with the environment. For example, natural computing techniques shape the interactions of assemblages so that they can carry out sustained interactions like growth and repair. They may also be directed towards accomplishing human-centered goals. For example, assemblage technology may fix dissolved carbon dioxide into a material form to produce self-assembling mineral structures, which was achieved in the 'proto-pearl' flasks in the *Hylozoic Ground* installation.

Most of the experiments that I have conducted using natural computing have been applied to the Bütschli system. Natural computing's outputs are consistent with the performance of non-equilibrium systems, which may be described by the laws of complexity. Unlike the inert objects that constitute a machine, the actants that comprise assemblages possess their own agency and result in a range of phenomena, such as emergence. Therefore, technological opportunities exist to directly and dynamically manipulate materials at far from equilibrium states in complex ways by developing spatial chemical programs. Yet natural computing is not about governing a discrete set of components but require orchestration of an entangled system of agents that interchangeably operate through emergent phenomena in various materials forms, such as fabric, software and hardware.

For example, the Bütschli system exemplifies how tightly fabric, software and hardware are coupled in natural computing processes. Bütschli droplets are produced when oil molecules, which may be thought of as a dynamic chemical program (both fabric and software), encounter alkali (both fabric and software) to produce soap-like crystals (both fabric and hardware), which form microstructures[50]. The overall performance of this system is shaped by many environmental conditions including temperature and local conditions like the movement of the droplets and the speed at which crystallization occurs.

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

Non-equilibrium chemistries operate through the ontology of assemblage technology that is qualitatively different than machines and consequently produce a range of unique phenomena. The hardware principles of this system are embodied in the droplet behaviour, which are not manufactured but self-assembled. Bütschli droplets self-assemble when an alkaline solution is added to an oil field, which spreads out and breask up into dynamic droplets about a millimetre in diameter.

Each droplet is an empowered object, agent, or actant, which possess an internal force that is powered by chemistry (or metabolism) and does not need an external energy source for it to exert its effects. Some of the properties are lifelike and these droplets can move around their environment, sense it and produce solids as a side effect of their metabolism. The droplets do not exist in series but work in parallel and are not organized hierarchically. They spontaneously form loose, reversible interactions, which form the basis of their assemblage operating system. Natural computing systems, therefore, inherently possess robustness, flexibility and the capacity to deal with external events.

Perhaps surprisingly, the technology is relatively conservative and is predictable within limits, except when tipping points in the system are reached. In the case of Bütschli droplets, populations may simultaneously change their shape and behaviour. The details of this process are still not fully understood. The technological principles of natural computing may be demonstrated in Bütschli droplets by changing the internal and external chemistry of the system. If mineral solutions are added to Bütschli droplets they can produce insoluble crystals in the presence of dissolved carbon dioxide. Populations of Bütschli droplets will also rapidly move toward a source of alcohol in their environment, which is likely to be caused by the reduction in surface tension by the solvent, although this has not been formally established.

However, for natural computing to be genuinely useful as a technology it needs to be readily applied at the human scale. While Bütschli droplet agents normally assemble at the microscale, it is possible to make them larger by slowing down their internal chemistry and engineering them to several centimetres.

When the droplets are placed within a constrained space, the chemical patterns that govern their interactions may be revealed as a consequence of the spatial restriction. An installation designed for the Synth-Ethic group show at the Bio fiction festival held at the Natural History Museum in Vienna in April 2011 introduced a two centimetre diameter spatial constraint to a modified preparation of the Bütschli system, which provoked the appearance of Turing Bands. This phenomenon is produced by diffusion and reaction patterns by chemical systems and is described by Alan Turing in his 'The Chemical Basis of Morphogenesis' paper[51]. Turing proposed that biological processes, such as gastrulation, animal skin patterns and specifically 'dappling', could be explained by this physical and chemical process. Today, these effects are attributed to the actions of information molecules such as RNA. However, since the lifelike properties of the Bütschli system are chemical, Turing's theory is actually responsible for the sinusoidal patterns produced in the system.

51 Turing, A.M. 1952. The Chemical Basis of Morphogenesis. Philosophical *Transactions of the Royal Society of London. Series B, Biological Sciences*, 237(641), pp. 37-72.

Natural computing is therefore susceptible to many influences. Since it possesses innate agency, the platform itself has the capacity to coauthor events that are relevant to design and engineering tasks. These tasks may be further shaped by humans through these techniques and constitute a form of 'soft' control.

Chemical assemblages are probabilistic systems that are influenced by many different factors, some of which I have just discussed. They are a promising potential design platform as they have the potential to evade the traditional binary divisions between various systems and modalities, such as Nature/machine, humanism/environmentalism and matter/information. In dissolving these divisions, natural computing may increase our choices in the way we design with materials and may help us to build ecologies. However, if it is to be socially relevant it needs to produce human-centred impacts.

Natural computing techniques were speculatively applied in the architectural project *Future Venice*[52], which proposed to attenuate the city from sinking into the soft delta soils on which it is founded. Programmable droplets were designed to grow an artificial limestone reef underneath the foundations, which stand on woodpiles, and could navigate the waterways using metabolic processes and natural computing techniques. Specifically, the droplets were designed to move away from the light and produce a limestone-like substance, or 'biocrete', when at rest. In the light-soaked waterways, the droplets would move towards the darkened foundations of the city and accrete around the woodpiles on which the city stands. Here, they would use dissolved minerals and carbon dioxide to accrete an artificial limestone-like structure under the foundations of the city and spread the point load. A natural version of this process already occurs along the canals and is carried out by the natural marine wildlife. It is hoped that the programmable droplets could work alongside the organisms to co-construct an architecture that is mutually beneficial to the marine ecology and the city.

52 Armstrong, R. 2012. Future Venice. In Myers, W. and Antonelli, P. eds. *Bio Design: Nature, Science, Creativity.* London: Thames & Hudson /New York: MOMA, pp.72-73.

Importantly, should the environmental conditions change and the lagoon dry out – say for example, Pietro Tiatini and his colleagues succeed in anthropogenically lifting the city by pumping seawater into its deflated aquifers, or if when the MOSES gates are raised in 2014[53] and the native ecology reaches a catastrophic tipping point - the programmable droplets would be able to re-appropriate their actions. As the waters subside, the woodpiles would be coated with a protective layer of 'biocrete' that stops them rotting when they are exposed to the air.

53 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.

Indeed, natural computing processes could be applied to the whole bioregion of Venice. Developing the right kinds of metabolisms and spatial programs could give rise to tactics that generate new relationships between natural and artificial actants to become the bedrock for forging life-promoting synthetic ecologies. Natural computing could potentially become a practice of shaping overlapping spatial programs and developing design tactics that enable a constant flux between fabric, space, structure and location. The outputs of the system do not imitate Nature but operate according to shared 'low level' programming principles that are applied through horizontal couplings between different populations of assemblages.

Still, natural computing does not propose a comprehensive solution to Venice's precarious future or indeed claim to end the legacy our environmental woes. Rather, it offers a convergent platform that enriches the available opportunities by which human and nonhuman communities may jointly respond to environmental events and challenges by codesigning their shared futures through the orchestrated construction of synthetic ecologies and weaving post natural fabrics throughout our living spaces.

Potentially, these approaches could give rise to a new platform to underpin human development as an alternative technological approach to digital computing and machines, which underpin industrial processes and offer ways of performing useful work that do not damage our ecosystems at their point of attachment to Nature, but strengthen them.

THE EVOLUTION OF ECOLOGICAL DESIGN

Dynamic chemistries are soft, permeable, mutable entities with presence. They can construct relationships and can transform one group of substances into another, not as inevitability, but as an occasional, asymmetrical event. Dynamic chemistries do not mimic natural systems or conform to already aestheticized notions that inform naturalism. Yet they work synergistically with Nature by sharing its language and constructing new possibilities using the hardware of matter and the language of metabolism. Dynamic chemistries are able to construct spatial programs that work toward an ecological design method through the production of new material hybrids. Further research and development of Natural computing methods may help us deal with 'ecological surprise', the unpredictable and transformational change in one or more natural systems that can be sudden, non-linear and catastrophic[53]. Indeed, dynamic chemistries may even facilitate a material politics that may help heal the metabolic rift that opened up with the growth of the modern economy, and catalyze a transition from an industrial to an ecological age as humans that are conceived through the lens of ecology rather than through the operational system of machines.

> … yet having felt the power
> Of Nature, by the gentle agency
> Of natural objects, led me on to feel
> For passions that were not my own …
>
> Michael: A Pastoral Poem. William Wordsworth

53 Lindenmayer, D.B. Likens, G.E. Krebs, C.J. and Hobbs, R.J. 2010. Improved probability of detection of ecological "surprises". *Proceedings of the National Academy of Sciences*, 107(51) pp. 21957-21962.