

An experimental approach towards characterizing Architectural Ecologies

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Abstract: This paper embodies an experimental architectural approach to the question of architectural ecologies. It defines and establishes a set of principles for this emerging practice and platform by providing examples of its proposals, as well as detailing areas for further exploration through a series of design experiments that are discovery-, rather than results-led. Projects include characterizing the nonlinear performance of Bütschli droplets in the laboratory and the ontological and epistemological challenges they raise. The paper also details architectural projects including the environmentally embedded, dynamic responses of living chemistries within Philip Beesley's cybernetic Hylozoic Ground installation and in taking an experimental approach towards establishing an environmentally contextualized reef to confer the foundations of a Future Venice with lifelike properties, thereby potentially transforming the fate of the city from inevitable destruction to potential survival. Finally, this paper reflects on how architectural ecologies may be applied experienced in wider urban environment through the production of Living Buildings through the establishment of new kinds of infrastructure. As such, this paper takes a position and vision for 21st century architecture through the emerging practice of architectural ecologies.

Keywords: Bütschli droplets, design experiment, experimental architecture, living buildings, ecological, Hylozoic Ground, Future Venice, architecture, manifesto.

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We are making a transition from an industrial epoch to an ecological one. This is not simply a matter of rhetoric, attitude or style – it is a genuine shift in the way that we think and live - for which we are not yet fully equipped.

1 Definition

“After a long period of often frivolous form making and unprincipled egoism in architecture, which have played into the hands of the most venal interests of real-estate developers and marketers, some architects are looking for more substantial ideas to serve, more meaningful goals to strive for, and the manifesto has come back. It is probably a temporary aberration, owing to an unsustainable idealism that lurks within statements of principle, but even their brief resurgence can help to regenerate—at least for a while— our beloved, beleaguered field.” (Woods, 2011)

Since there is no formal definition of architectural ecologies, I will, for the sake of clarity outline the principles that shape my own practice in this paper. This essay therefore serves as a manifesto and experimental tool that I will use to develop a series of design experiments that extend the propositions implicit in the concept of architectural ecologies and refine them through a series of projects.

Architectural ecologies are about the changes that accompany the transition from an industrial to an ecological era, where the term ecology has come to be popularly equated with ‘general systems’ thinking (Von Bertalanffy, 1950). The concept reflects a need and zeitgeist within contemporary design practice and society to reach escape velocity from the expectations of an Enlightenment culture to embrace new qualities of existence such as, openness, interconnection and transformation. In challenging our values, perceptions and relationships with all aspects of existence, we may conceive and produce the spaces in which we are immersed, in new ways.

In keeping with architecture’s cross-disciplinary nature, the forms of inquiry embedded in architectural ecological practices, draw together strands of thought. They relate to a complex reality in constant flux, characterized by notions of impermanence, change, instability, flow, complexity, probability, chaos, uncertainty and emergence. Through their convergence, architectural ecologies produce new ways of making, which are characteristic of living systems. They have evolved to embody, process and embrace change, which are qualities that are woven into the very fabric of the natural world.

With their affinity for the natural realm, architectural ecologies embrace a rich, multi-disciplinary history of systems thinking that includes William Blake’s notion of ‘evanescence’, Henri Lefebvre’s Rhythmanalysis and James Lovelock’s notions of Gaia. They share a muddy history with general systems theory through holism, cybernetics, the environmental movement and even space exploration. Yet they also embrace cutting-edge, experimental attitudes through which they synthesize a constantly evolving future, which speak to Ilya Prigogine’s dissipative structures (Glansdorff & Prigogine, 1971), David Deutsch’s quest for quantum computing and to the rise of advanced biotechnology like J. Craig Venter’s total cell reprogramming dubbed ‘Synthia’ by the popular press.

Architectural ecologies also enable the reunification of the biotic and inorganic realms, which were alchemically cleaved as distinct fabrics during the Enlightenment. Instead they provide access to a host of technological and natural elements that make up our urban environments (Harvey, 1996). For example, where modernism has demanded purification,



architectural ecologies seek recomplexification of reality through strange entanglements with matter, life, society, culture, science and technology.

Through the incessant vacillation between emerging technologies and enduring concepts, architectural ecologies reinvigorate the present and restructure the many futures we face. Architectural ecologies possess the potential to make radical breaks in order and materiality by reaching tipping points of transformation where at these junctures, it may be possible to harness their originality and make a full transition from an industrial era to an ecological global culture.

2 Context

Following a generation of digital natives we are living in a contested reality where traditional boundaries – geographical, disciplinary, cultural, ideological, economic, political and temporal - are being transgressed.

Within these violations of established order, notions of identity are being uprooted and conditioned by the uncertainty of change. Rather than the reassurance of a job for life, a place within the social hierarchy and a sense of stability – the current generation is being faced with constantly changing needs, contexts, choices, circumstances and allegiances. Yet, although these inexactitudes bring unemployment, austerity, placelessness and insecurity, which erodes long-term commitments - they are also accompanied by fluidity and freedoms that enable social mobility, cultural plasticity. Indeed, they constitute a melting pot for societal convergences – technological, political, economic, ideological, material, ecological – and are a bedrock of creativity.

Yet the tools that are available to navigate the constantly changing context of the living world remain rooted in modern industrial paradigms. These are designed to function within a reality that is imagined at equilibrium, characterized by its fixity and hierarchical orders.

3 Design Methodology

Architectural ecologies have something new to offer the study of general systems theory and associated sciences in that they bring a design methodology to the toolsets through which the inconstant nature of reality may be explored. I will address this particular approach through the specific perspective of experimental architecture, a term coined by Peter Cook, which refers to a visionary architectural practice (Cook, 1970) exemplified by the work of Archigram in the 1960s and 1970s and by Lebbeus Woods (Woods, 2012). My work follows in this tradition but does not use drawing as the experimental medium but rather draws on a range of practical design experiments that lead to models, prototypes and further mapping of architectural concepts. Design experiments differ from scientific investigations in that their focus is on exploration rather than resolution and while they apply many of the same techniques and technologies associated with traditional scientific approaches, their focus is on discovery and the formulation of new questions, rather than search for specific products, or solutions. This means that by its very nature design experiments are probabilistic and are shaped by their context, material, technologies, specific methods and even experimenter preferences and experiences. Yet, while they are not reproducible in the same way as a scientific experiment, they constitute a valuable experimental psychogeography of possibilities through real and reproducible phenomena such as, self-organization, self-assembly and emergence.



Design methods are process-led and are therefore immersed in the worldview of general systems theory. Since their role is as an avatar for exploration within an uncertain terrain, experimental architectural approaches are equipped to deal with contradictions and operate for example, within orders where relative stability and volatility may co-exist such as, in dissipative systems. Such design methods do not depend on controls, reproducibility, or need to be corrected for incidental errors. Rather, they grapple with the messy complexity of circumstance, chance and experimenter uniqueness. This enables them to work with the peculiarities and particularities of systems, and resist the seduction of theories of everything, generalizations and idealized solutions. Within the practice of design experiment, architectural ecologies seek toolsets through which it is possible to frame 3rd millennial concerns in new contexts from radically different perspectives. Yet since these are distinct from an atomistic worldview, they are hard to embody as the technological history of working with dynamic systems realities back to ancient practices such as, gardening, agriculture and cooking. These traditions of making and manipulating are heavily invested in working with a world we can command and precisely control. Such forces characterize the natural realm, which is far from obedient and subject to our control. Indeed, our view of Nature is deeply entangled with the material realm and is also associated with the figure of the nonhuman.

At the heart of an industrial attitude towards these nonhuman agencies is an understanding that matter is inert, brute and requires instruction by an ephemeral essence such as a human mind, software program, spirit or vitalism. Indeed, over the course of the 20th century we have constructed a simplified image of Nature, whereby it is an adversarial force on one hand and in danger from us on the other. The modern attitude therefore requires us build walls against it – or to protect it, keeping its inconstancy and fragility at a distance from our seemingly ordered lives. Indeed, the rise of biospheres pioneered by Christopher Alexander and Richard Buckminster Fuller, which are sites of constructed natures that have become accepted as the symbol of ecological thinking, have prioritized functionalism as a valuable design attribute and seal ecological concerns off from a wider, complex reality. Such attitudes, whereby the natural realm is a closed, efficient chain of materials, have rendered notions of ecological design rather unimaginative, industrial, culturally erratic and insular in architectural practice. Indeed, in our mechanical urban spaces, we have adopted this insularity from the natural world a design approach so that it is necessary to accommodate aestheticized versions of Nature, which are reserved for tidy green rooftops, geometrically shaped fountains, or patterned vertical walls. Yet, in these same spaces, we abhor pigeon guano, cockroach infestations and various crypto-geographies, which are communities of microorganisms that stain buildings by their specific inhabitation of niches created at the intersection of architecture and microenvironments¹.

However the matter that constitutes the natural world is extremely lively, strange and capable of operating independently from human influence. Indeed, the autonomy of matter is appreciated by process philosophy, which is concerned with the idea of 'becoming' as a primary quality of experience both for humans and the material world (Seibt, 2013). Process philosophers share a set of principles that view reality as an entanglement of physical, organic, social, and cognitive processes. Yet, within this broad framework, process philosophers - such as, Heraclitus, Gottfried Wilhelm Leibniz, Georg Hegel, Friedrich Nietzsche, Martin Heidegger, Jacques Derrida, Alfred North Whitehead, Henri Bergson, William James and John Dewey differ in how they propose a world forged by process is construed and in their choice of theoretical style.

¹ The term crypto geography was coined by microbiologist Simon Park, who details his observations photographically in an online journal at: <https://microgeography.wordpress.com/> and also at: www.exploringtheinvisible.com



From these perspectives an image of the natural world that is consistent with a constantly changing material realm may be constructed. Such a perspective forms a counterpoint to the modern view of nature and may be thought of as Millennial Nature.

'Millennial Nature' is not the bucolic, untouched wilderness that the Romantics swooned upon but a version of Nature that has been deconstructed and stripped of its aestheticisms to reveal its raw, relentlessly material character (Morton, 2007). Millennial Nature is not an Enlightenment "*standing reserve*" (Heidegger, 1993) that awaits mechanical instruction, nor is it an anti-modern, vengeful force that seeks to usurp humankind. Rather, it is forged through the horizontal coupling² of different species of lively material agents, which negotiate many difficult relationships through the production of assemblages. Yet these are not utopian fabrics devoid of struggle, or contradiction but are wilful and must be managed – not repressed – so that its constituent assemblages may respond favourably to human requirements. Millennial Nature is not anti-human but is a child of multiple parents from the environmental movement, space age, digital revolution and biotechnological era that seeks to reach escape velocity from the binds of industrialization through forging a new relationship with humanity, which demands to be engaged and nurtured, not tamed. Owing to its hybrid origins embraces many different substrates such as, inorganic agents, biological systems, weather, geological forces, soils, oceans, atmosphere, gravity, light, star systems, black holes and humans. Indeed, Millennial Nature is the fabric of reality, at all scales, which can only be perceived in relationship to human activity – but which acts entirely independently of us. Millennial Nature is not just an alternative organizing system but possesses technological characteristics that construe an alternative production platform than machines for the synthesis of new systems and fabrics.

Indeed, the empowered fabrics of Millennial Nature actively participate in our contemporary socioeconomic and political systems. They demand to be accounted for and require us to overhaul our political and social thinking such as, in Donna Haraway's companion species manifesto (Haraway, 2003), Karen Barad's agential realism (Barad, 2007), Jane Bennett's vibrant matter (Bennett, 2010), Myra Hird's bacterial microontologies (Hird, 2009), Bruno Latour's Actor Network Theory (Latour, 2005), and Timothy Morton's Ecology without Nature (Morton, 2007). All these authors reimagine our relationship with the natural realm appreciating that humanity does not exist in isolation in closed ecological loops, but are situated within an open reality in which matter can be freely exchanged.

It is within this cultural context that architectural ecologies speak so powerfully to design cultures, which are concerned with multiplicities, parallel worlds, augmented realities, quantum fabrics, flux and mutability. Through their rhizomic nature, they gain traction with their material, methodological, technological and societal agendas. Architectural ecologies seek convergence with emerging platforms that promote ruptures in social, environmental and economic order through material condensations where distinct media merge and materialize through bodies whose qualities of performance cannot be predicted by knowledge of their ingredients. Architectural ecologies are transformers of matter and experience that convert emerging media – biotechnology, nanotechnology, information technology and cognitive technologies - that are currently framed by industrial expectations, into something new, strange and fundamentally creative. By drawing on the parallel processing power of the physical realm architectural ecologies unleash their synthetic powers to create porous interfaces and hybrid materialities that form the sites for multiple new experiences such as, bioelectricity, crystalline computing and the embodied plasticity of

² By 'horizontal coupling' I mean the propensity for all matter at all scales to form relationships through subatomic interactions and the forging of molecular bonds so that there is effectively no top-down, or bottom-up hierarchical ordering but continual negotiation between assemblages that occurs at all scales.

the super polymer DNA. These experiences are embodied in the production of new fabrics with new creative potentiality that manifests through tipping points in design, order and the way we make things.

Yet these ambitions are not new. Cybernetics aimed to emulate these dynamic processes that are typical of life through classical engineering paradigms – or ‘systems’ engineering. While cybernetics largely based its practice in mechanistic systems where control systems – not the materials – performed the decisions and work, architectural ecologies seeks new platforms that are not based in classical mechanics. Gordon Pask and Stafford Beer experimented with some of the design possibilities offered by empowered materials, by considering them as cybernetic systems. Pask explored crystal formation in response to street sounds (Bird & Di Paolo, 2008, pp.185-212) and Beer used the microorganism daphnia – a microscopic crustacean commonly known as the ‘water flea’ – as well as entire pond ecologies as alternative media for cybernetic systems (Beer, 1994). Yet, their ability to manipulate material systems through positive and negative feedback loops alone, became quite limited from a design and engineering perspective, particularly since the emerging field of biotechnology was not mature. Yet, over the last few decades the chemical operations of lively materials have been characterized in fine detail to the point where biochemical processes within living systems – called bioprocesses - are not just a material substrate but also, simultaneously double up as the technical system through which these substances are instrumented. These are applied in a range of design practices from harnessing the properties of the living world through their bioprocesses, to actually redesigning the very fabric of life (Cronin et al., 2006; Cairns-Smith, 1987). How designers and engineers cope with the new tolerances set by living systems so that they may embrace the laws of probability and claim their stake as a co-designers of a system, is all part of an architectural ecological worldview. Currently such practices are embodied in soft robotics and morphological computing, which consider distributed, not centralized control systems and in unconventional computing processes that harness non-Van Neumann architectures and Turing codes. In short, an architectural ecology is an experimental attitude through which new ways of designing and engineering that are not constrained by classical systems may be conceptualized and realized. As such, there is much speculation in the current practices, which are interrogated through physical experiment to find new spaces in which to place questions, explore and invent alternative roads towards our shared futures.

4. Protocells as a unique technical system

Protocells are “primordial molecular globules, situated in the environment through the laws of physics and connected through the language of chemistry” (Spiller & Armstrong, 2011)

A turning point in the evolution of lifelike technologies, have been reached through ‘protocells’. They represent a unique convergence between what Kevin Kelly calls “*the born and the made*” (Kelly, 2010) and take the form of range of smart chemical assemblages that demonstrate striking lifelike properties, which have been constructed from a bottom up perspective from fundamental ingredients. In some cases such as, the Bütschli droplet system, they able to move around their environment, sense it, operate as populations of agents and even produce microstructures (Armstrong & Hanczyc, 2013). Protocells have not been found spontaneously in Nature and are therefore entirely artificial, being the product of human observation, design and engineering goals. Protocell species are prototypes of

primitive cells, whose primordial nature is related to the bottom-up approach taken towards development of an artificially constructed cell. Owing to a growing interest in the field, a range of approaches, definitions and types of protocell species exist. The controversial and ambiguous nature of the term invites a broad range of definitions. Its etymology implies a chemical agent that possesses some of the formal qualities of 'life' such as, movement, sensitivity, metabolism, growth or repair, yet is not given the full status of being fully alive. However, sometimes the term has been used interchangeably with 'vesicle', while at other times it may indicate fully artificial chemical cells capable of replication. In this current investigation the term is used to refer to real cell models that to date, exhibit a range of recognizably lifelike qualities but do not qualify as being fully 'alive'. Specifically, the Bütschli system – a water in oil dynamic droplet system, is used as a model to reflect on the potential of a broader portfolio of agents that may also be described as 'protocells'.

5 Protocells and design

Protocells represent and embody the convergence of natural and artificial systems. Such contradictory qualities may be meaningfully employed as agents of design when their properties and interactions can be choreographed through deliberate interventions using the programming language of chemistry that resides in the fundamental properties of atoms. Precedents already exist within molecular biology where bacterial interactions are described as being enabled by a chemical 'language' with 'words' (Schauder, 2001) that can influence non-bacterial agents and may be capable of combinatorial linguistics (Scott-Phillips, Gurney, Ivens, Diggle & Popat, 2014). Such findings are preliminary but suggest that sophisticated communication systems may not be exclusive to large, centrally organized brains and molecular interactions are semiotic tools for bacteria. Yet the broader association between language, cognition and bacterial communication systems is still being defined and much further work needs to be done to verify the importance of these discoveries in this controversial field. To establish a technical system that could provoke material transformations for design applications, an experimental model was therefore required that could engage with a chemical language, which could also influence the lifelike chemical principles of protocells. For practical purposes, it was also necessary to select a platform that was readily observable at the human scale, as well as operating within timeframes conducive with conventional design and laboratory practices.

6 Design dialogues through experiment

Dynamic droplets are self-assembling agents that are composed from different recipes (Armstrong & Hanczyc, 2011) that are based on the chemistry at the interface between oil and water where there is a spontaneous self-assembly of molecules. The consequences of mass interactions are observed in the system as emergent phenomena that typically exhibit life-like behaviour such as, movement, which can be observed and characterized. They are restless, inherently creative agents that ceaselessly patrol and reposition their chemical networks and interactions. Dynamic droplets are influenced by internal and external factors and therefore amenable to design interventions.

One particular species of dynamic droplet, the Bütschli system was examined in further detail from a design perspective. Zoologist Otto Bütschli originally described this recipe in 1892, when he added a drop of strongly alkaline potash to olive oil (Bütschli, 1892).



The experimental design was modified to suit a modern laboratory and Bütschli's original ingredients were interpreted into a workable, hand-delivered system where 0.2 ml drop of 3M sodium hydroxide was added to olive oil in a 3cms diameter Petri dish. This was filled to a depth of 0.5 cm with extra virgin olive oil. These ingredients combine through a saponification reaction, in which the triglycerides of the olive oil are cleaved to produce free fatty acids and glycerol. The main ingredient of olive oil is oleic acid that constitutes around 61.09% to 72.78% depending on the source. The same brand of oil, Monini extra virgin from Spoleto, Italy, was used exclusively in this experiment although it is not known whether different bottles came from the same production batch. All ingredients were used at room temperature.

Controls included adding a 0.2ml drop of water to a 3cm diameter petri dish filled to 0.5 cm deep with olive oil and also by adding 0.2 ml 3M sodium hydroxide to a 3cm diameter glass bottom petri dish filled to 0.5 cm deep with canola oil (Rapeseed), from Cargill Oil Packers, which is around 85% oleic acid. Systems that included a titration of sodium hydroxide were also performed.

The lifelike qualities of the Bütschli system have not been formally recorded other than through Bütschli original hand drawings (Bütschli, 1892) and therefore required full characterization before the technological potential could be evaluated (Armstrong & Hanczyc, 2011). The behaviour and morphology of this system was observed and characterized in detail using a Nikon Eclipse TE2000-S inverted microscope with Photometrics Cascade II 512 camera and in-house software under light microscope for approximately 300 replicate experiments under the standard conditions. Dynamic droplets were produced during a variable window of time (from 30 seconds to 30 minutes after the addition of alkaline water to the oil phase) and were photographically documented. Lifelike self-organizing patterns were observed that provided a means of introducing temporal and spatial order in the system and created a platform further chemical programmability.

7 Observations

On addition to the olive oil, the strongly alkaline solution quickly broke up into organizing fronts of chemical activity and a collection of centrally placed droplets emerged from the reaction fields that were about a centimeter in diameter. The droplets were an ideal model system for observing complex material relations over short time scales that lasted up to an hour. They were inexpensive to produce, could be readily viewed at the human scale and demonstrated lifelike emergent properties. Using a modern light microscope, the droplets exhibited a range of phenomena such as, movement, group interactions, microstructure production and environmental sensitivity. See figure 1 for a series of micrographs depicting a range of interactions observed in the Bütschli system³ and also tables 1-3 as a summary of findings (Armstrong & Hanczyc, 2011).

³ The stages of the lifespan of Bütschli droplets were organized into morphological and behavioural phases of pattern progression that occurred during three distinct stages:
Birth (0 – 5 minutes)
Life (30 seconds – 30 minutes)
Death (0 - 30 minutes)

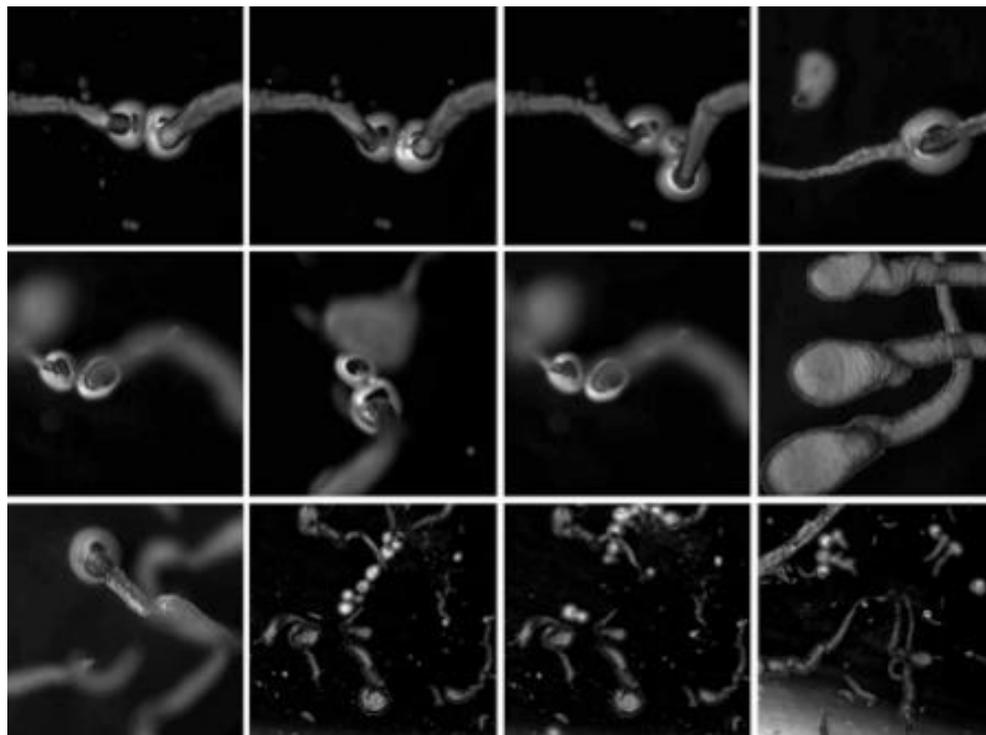
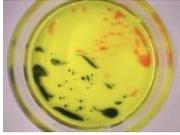
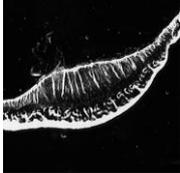


Figure 1: Complex structures produced by dynamic chemistries may relate to the spatial complexity produced by metabolisms, which enable the evolution of complex structures that are characteristic of organic life (Micrographs and collage, Magnification x4, Rachel Armstrong. February 2012.)

Table 1: Birth stages of Bütschli dynamic droplet formation			
Time after addition of alkali to oil phase	Photograph of phenomenon	Pattern Morphology	Comments
20s		3.5 cm petri dish. Early movement dispersion of droplet and breaking up of the chemical wavefront due to changes in surface tension.	Macroscopic view of Bütschli system.
50s		3.5 cm petri dish. Progressive movement and dispersion of droplet and breaking up of the chemical wavefront due to changes in surface tension.	Same preparation as in figure 1 after the passage of 30 seconds.
8s		6 mm width of micrograph. Polarized field of 'Fire' and 'Ice'.	The leading 'fire' edge is facing downwards and the trailing 'ice' edge is facing upwards in the micrograph.



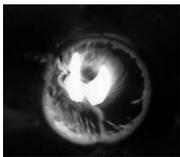
	<p>6 mm width of micrograph. Turbulent, shell-like droplets appear as a series of sequentially emerging manifolds.</p>	<p>Some 'shells' collapse while others self-organize into droplets with life-like properties such as, movement.</p>
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Table 1: 'Birth' stages of Bütschli dynamic droplet formation

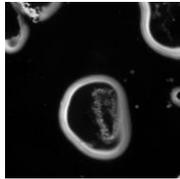
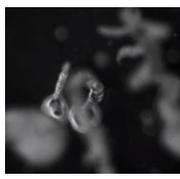
Table 2: Life stages of Bütschli dynamic droplet formation			
Time after addition of droplet to oil phase	Photograph of phenomenon	Pattern Morphology	Comments
2min 30s		<p>300micron width of micrograph. Motile, droplet emerges from the chaotic chemical field of strong alkali in olive oil.</p>	<p>Crystalline material is visible accumulating at the oil/water interface at the posterior pole.</p>
3min		<p>6 mm width of micrograph. Droplet with osmotic crystalline deposit.</p>	<p>Crystalline material is visible as an osmotic microstructure attached to the droplet at its posterior pole.</p>
8min		<p>300micron width of each micrograph. Osmotic structure seen with and without fluoroscopy in which the Bütschli droplet has just detached from an osmotic structure.</p>	<p>These micrographs are of the same structure at the same magnification.</p>
10min		<p>6 mm width of micrograph. Growth of osmotic structure.</p>	<p>Bütschli droplets produce deposits of sodium oleate at the trailing end of the motile droplet where they accumulate and extend to form fluid-filled microstructures.</p>
2min		<p>6mm width of micrograph. Bütschli droplets before fusion.</p>	<p>Fusion events are spontaneous & may be the generative agency for the production of compound, complex, osmotic microstructures.</p>

Table 2: 'Life' stages of Bütschli dynamic droplet formation

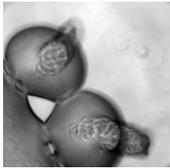
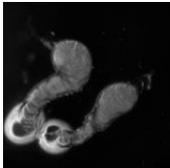
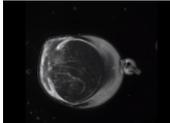
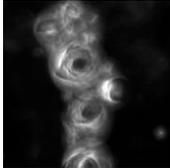
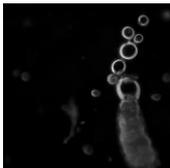
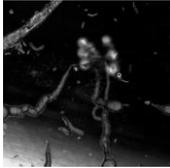
Table 3: Death stages of Bütschli dynamic droplet formation			
Time after addition of droplet to oil phase	Photograph of phenomenon	Pattern Morphology	Comments
8min		300micron width of micrograph. Interfaces between droplets persistently osculate.	Two Bütschli droplets engage active interfaces generating various, dynamic points of contact. They continue to make contact until the reaction product (sodium oleate crystals) obstructs the interface between them.
12min		6mm width of micrograph. Bütschli droplets 'mirroring' one another.	Mirroring may be a phenomenon related to self-similar microenvironments in a medium but needs further exploration.
12min		6 mm width of micrograph. A smaller Bütschli droplet is interfacing with a much larger one.	Droplets remain in close proximity with each other, possibly attracted and repelled by reaction products, until the build up of soap crystals occludes the oil/water interface.
8min		6 mm width of micrograph. Bütschli droplets in a simple chain formation.	Periodic oscillations are observed in agents during a chain-forming event.
10min		6 mm width of micrograph. Bütschli droplets in a complex chain formation.	'Protocell roses'.
15min	 	6 mm width of micrograph. Two droplet assemblages merge and suddenly change behaviour and morphology.	Phase change behaviour and morphology may be observed during the formation of droplet assemblages when a 'tipping' point is reached. The specific conditions under which these events occur has not formally established and warrants further investigation.

Table 3: 'Death' stages of Bütschli dynamic droplet formation

From these experiments it was possible to observe that Bütschli droplets possess a set of simple operations that originate from an internal force that is conferred by its metabolism.



This provides the energy that the droplets use to exert effects on their surroundings. They can move around their environment, sense it, and even produce products in parallel forms of organization and without a hierarchy of order. These spontaneous groupings make loose, reversible interactions between each other and generate the flexibility, robustness and environmental sensitivity of the system. These interactions provide a set of morphologies that relate to the spontaneous creativity in the system but which evade simple definition.

8 Ontological and epistemological issues raised by Bütschli droplets

Owing to the continually changing nature of the Bütschli droplet outlets, ways of classifying events within the system were considered. Each droplet possesses a set of properties that are not fixed but are continually transforming themselves through interactions between themselves and their environment. These exchanges also create the conditions in which further populations of droplets move through and perform within the reaction field.

The Bütschli system potentially offers a technological platform that exhibits non-classical behaviours, which invoke a distinct set of concepts that are different to those of classical technical systems. While Bütschli droplets may be framed within the language of process philosophy and scientifically characterized through the principles of complexity, observing the system is inevitably mired in deterministic concepts and aesthetic expectations (Morton, 2007). This makes it difficult to view and describe the constantly changing Bütschli system without trying to establish its performance within pre-existing knowledge sets. Yet this is exactly what needs to be done if the full potential of this emerging technology is to be fully explored and imagined. Indeed, the Bütschli system may yet prove to be 'post-epistemological', or unclassifiable in any coherent, meaningful way using traditional modes of classification such as, the system proposed by Carl Linnæus. Currently, there is no classification system to characterize dynamic lifelike chemistries. Of interest is Linnæus' taxonomy of stones, which he asserted possessed some of the properties of living things. In fact, Linnaeus suggested that stones grew by way of an accretion process such as, when sand aggregated and became sandstone or, when the apparent clumping of clay particles formed limestone.

Although man-made, and in that sense 'artificial', the lifelike performance of the Bütschli system provides an opportunity to consider the emergent characteristics as a subset of living qualities in order to construct a more thorough understanding of the system as a whole. Indeed, the approach taken in reporting the observations is relevant to current systems of classification used in biology and natural history, which may help relate non-living phenomena to biological systems through a description of their pattern morphology. There is much to be learned through comparative analysis and my research attempts not only to observe, but also to construct an understanding of the characteristic of the lifelike properties of the Bütschli system as the basis for further study.

Conventionally, dynamic systems are described by recognizing geometric domains such as, patterns and metapatterns. Yet, there are semantic problems with such an approach since pattern-recognition infers – rather than reveals – underlying processes. For example, very similar patterns may be generated within completely separate media such as, DNA producing mollusc shells that are physical systems, and the graphical modeling of shell-like structures on a computer screen, which are virtual systems. As a way of reading transformational events within nonlinear fields of action, Matt Lee uses the term 'oceanic

ontology' to create maps of complex processes (Lee, 2011) that offer an alternative classification system to documenting snapshots of a dynamic system through time. To test this approach, an oceanic ontology of the Bütschli system was produced that drew on observations from the 300 replicate Bütschli experiments and subjectively mapped specific relationships using exploratory graphical approaches, see figure 2.

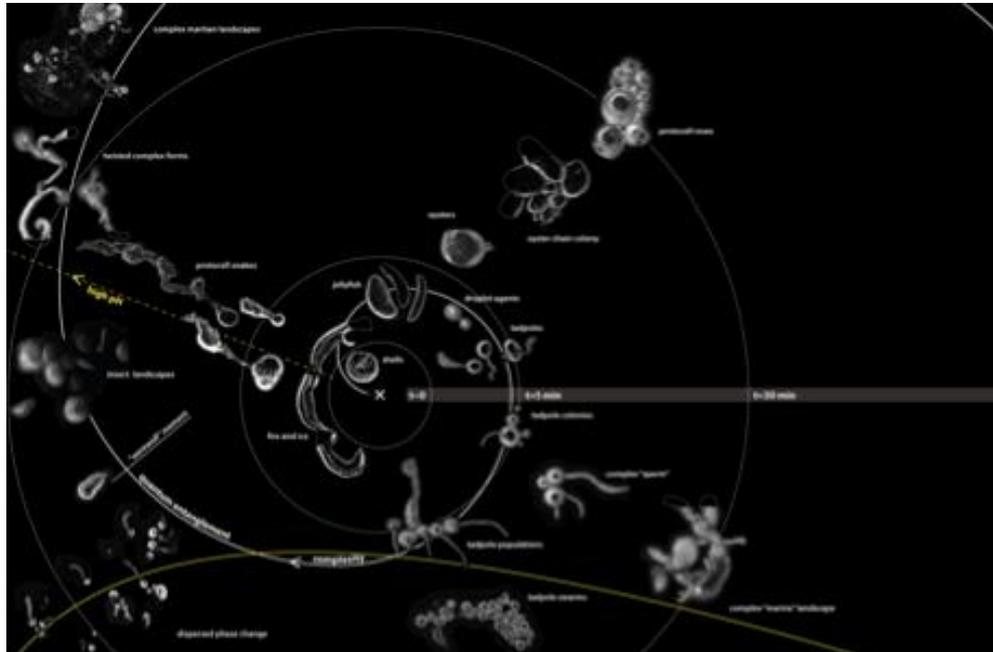


Figure 2: This diagram depicts dynamic droplets as 'actors' that operate within the many variable influences encountered in their oil field as an ontological 'map' of events. While the diagram is drawn as a 2D topology, the possible events within the field are manifold and open up multi dimensional spaces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

The diagram is centred at time zero from which concentric circles radiate, representing an exponentially increasing series of time intervals. This logarithmically increasing function proposes to encapsulate the intense self-organizing activity that happens early on in the chemical reaction and falls off rapidly with the passage of time. An estimated ninety per cent 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 that also radiates from the origin and depicts the high frequency of events around the start of the reaction that becomes less frequent as time unfolds. The various morphologies and behaviours that indicate change in the system are subjectively grouped according to the authors' experimental findings and interpretations. For example, the complex oyster chains are distinct in appearance but only differ by degree, from the complex marine landscapes. Specifically, 'oysters' produce a large mass of material and their soft bodies bulge from their material shell-like tethers, which anchor them, as shown in figure 3.



Figure 3: Oyster-like, thick, osmotic structure produced by dynamic droplets (Micrograph, Magnification x40, Rachel Armstrong. February 2009.)

In contrast, 'marine landscapes' are composed of a variety of largely inert forms that have been produced by droplets that would previously have been described as 'oysters'. However, the undulating droplets are long gone leaving only a trail of residues behind them, as shown in figure 4.



Figure 4: Thick, osmotic structures being produced by dynamic droplets that are moving away from their deposits and producing 'marine landscapes'. (Micrograph, Magnification x4, Rachel Armstrong, February 2009.)

The diagram in figure 2 also indicates the impact of chance events from a source external to the system as an incidental trajectory that intersects with the fundamental progressive vectors of the Bütschli system. It represents disturbances in the environment, such as changes in ambient temperature, or incidental vibration. This external vector also touches the spiral of complexity and in this case, implies that in this specific context, agents within the system could reach tipping points.

However, while attempting to navigate relationships between events, the diagram in figure 2 does not propose an empirical tool but makes use of graphical qualities and metaphor to convey complex occurrences within the reaction field. For example, the 'werewolf moment' is characterized by extreme droplet agitation and the rapid production of residue, which bestows it with a rather 'hairy' appearance. This striking event is most likely precipitated by the ratio between droplet surface area and the volume of the droplet that are optimized and therefore rapidly consume the dynamic agent. The rapid precipitation of product over the droplet surface causes drag that precipitates erratic movement. This excitement phase typically lasts for around a few minutes and produces a large amount of residue. This is swept to the posterior end of the droplet by molecular action and physical forces, where it is suggestive of a 'tail' that exerts a great deal of drag on the system. This series of complex events immediately precede droplet inertia as the dense precipitation extinguishes the droplet metabolism by completely occluding the interface. The werewolf moment is therefore a pre-terminal event for the droplet, since its outcome is quiescence.

The Bütschli system represents an active chemical body that is at far from equilibrium and shaped by its context. It possesses distinctive material programs that confer the system with recognizable characteristics and patterns of behaviour, which exist within a silent network of material systems that are conjured when substances are mixed. Such phenomena resist empirical definitions and court a post-epistemological status, which questions existing categories and identities that take place within much broader field of events. Indeed, this realm has become so naturalized that it has receded into the background of our daily lives as a matrix of constant production, which Bruno Latour refers to as OOWWAAB (Out Of Which We Are All Born) (Latour, 2013). Of course, this dynamic field of chemical transformations is culturally recognized as Nature, and embodies a vast horizontal plane of making, from which life on Earth has sprung.

In the natural realm boundary interactions are not exclusive to the behaviour of populations such as, flocks of migrating birds, schools of dolphins, or dynamic droplet assemblages, but also exist as strong and weak forces between objects including gravity, electromagnetism, strong and weak nuclear forces. These generate a host of interactions including, attractions, repulsions, amplifications and extinctions that may be observed at the interface of trembling dynamic droplets, which are infused by the medium in which they exist to exert effects on the ordering of material relationships. This creates a synthetic scenario that builds new groupings, identities and forms of order that constantly propose new networks of operations through which living systems may constantly adapt and evolve. It is within this technical context of natural systems that it may be possible designing with dynamic material systems in new ways.

9 Examples of architectural ecologies

9.1 Hylozoic Ground Chemistries

The Hylozoic Ground is an installation by architect Philip Beesley, which was Canada's national entry for the Venice 2010 Architecture Biennale (Armstrong & Beesley, 2011). The Hylozoic Ground installation consists of a cybernetic matrix with a primitive neural network and sensory actuators that allowed the system to interact with a gallery going public. It provided an evolving experimental platform that visualized and shaped the material connectivity, novelty and transformation that already takes place within natural systems (represented by the gallery environment) and coupled them with artificial systems (the cybernetic matrix). A series of dynamic chemistries were designed to connect the cybernetic matrix and gallery through a different kind of interface that enabled material transformations to take place over the course of the 3-month installation. These Hylozoic Ground chemistries served as natural computing models that could respond morphologically, chemically and poetically to the installation's themes and programs, specifically by responding to the expired carbon dioxide of the gallery visitors and its accumulation within the installation site. The work explored notions of 'life', ecology, the quality of spatial experience and dynamic systems. The question of scale was implicit in this design challenge and for example, the millimetre scale field of action of Bütschli system could be further increased to the metre scale. This was achieved both by slowing down the metabolism of the droplets and also by entangling distributed populations of the chemistry in flasks within the cybernetic matrix. Dynamic chemistries enabled artificial and natural agents to form notional ecological networks within the gallery space that included installation, audience and environment, see figure 5. These exchanges took place through the hardware

of dynamic chemical objects and metabolic software that enabled the deliberate modification of these networks by the range of actors within the system. While the underlying metabolic systems are sufficiently robust to accommodate local disturbances, the redistribution of chemical flows within these networks was poetically proposed to possess the potential for producing new kinds of Nature whereby the synthetic ecological exchanges were poetically likened to the material complexification and diversity that shapes the proto-ecologies of natural systems. These arise from an existential sea of deeply entangled, mutable, transitional and ambiguous agents that are subjected to selection forces, which enable some configurations persist, transforms other and causes many to wither.



Figure 5: Hylozoic Ground installation, Canadian Pavilion, Venice is a cybernetic matrix that integrates a range of different 'organ' and 'tissue' types such as, swallowing tubes (tapered cylindrical structures to the right of the photograph) and sound organs (clustered leaf-like structures in the centre of the photograph). The challenge was to design a set of dynamic chemistries that would aesthetically and functionally complement the soft mechanical systems. A centrally placed (yellow) chemical organ can be seen centre field (Photograph, courtesy Philip Beesley. August 2010.)

9.2 Future Venice

Future Venice is an architectural project that imagines an alternative sustainable future for the city by growing a synthetic reef under its foundations. It is experimentally developed through the actions of a range of modified dynamic droplets, which act as an urban scale natural computer.

The droplets are designed to move away from the light and use dissolved minerals and carbon dioxide when at rest, to collectively produce a kind of 'biocrete'. Droplet titration as required, is used to 'grow' the structure by adding aliquots of self-assembling mixture to the light soaked waterways of the city. Once in the canals, the droplets are programmed to move towards the darkened foundations that stand of narrow woodpiles and gradually produce a biocrete accretion technology. This spread the weight of the city over a much broader base and attenuates the city from sinking into the soft delta soils on which it was founded (Myers & Antonelli, 2013, pp.72-73).

Of note, the marine organisms in the waterways already produce a kind of biocrete and it is anticipated that the protocell system will work with the marine animals to co-construct an architecture, which is meaningful to both the creatures of the lagoon as well as the city inhabitants. Should the environmental conditions of Venice change and the city dry out rather than drowns as currently predicted, then the system could potentially change the range of its outputs. Rather than growing sideways to spread the minerals over a broad

base, the accretion-producing droplets may deposit their material on the woodpiles, sealing them from the air and stopping them from rotting, see figures 6-7.



Figure 6: View underneath Venice's foundations that stand upon woodpiles demonstrating the potential action of a city scale morphological computer composed of smart, programmable droplets. This speculative assemblage-based technology proposes to harness the collective action of light sensitive droplets that are programmed to move towards the darkened foundations of the city to grow an artificial limestone reef. This structure aims to gradually spread the point load of the city over a much broader base than offered by the narrow woodpiles as well as providing new ecological niches for the marine wildlife.(Computer drawing, Christian Kerrigan. February 2009.)

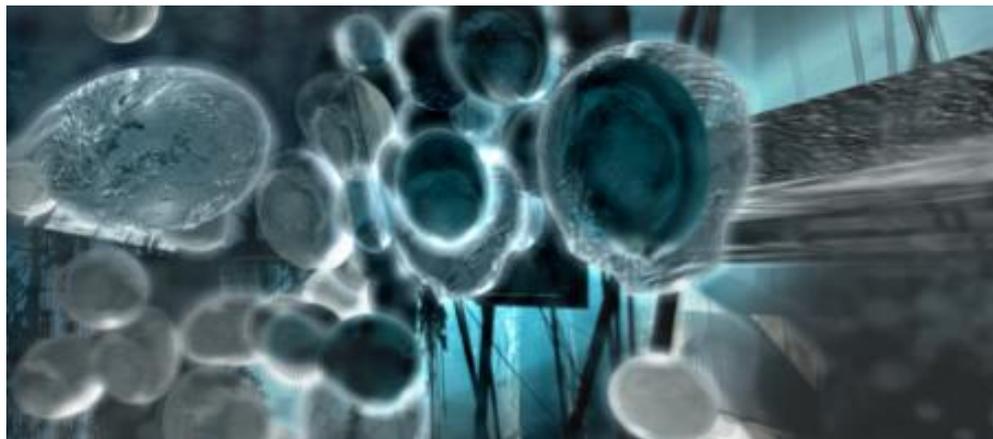


Figure 7: View of programmable droplets coming to rest underneath Venice's foundations as their light sensitive metabolism reaches equilibrium and activates a second metabolic process that enables the droplets to use local minerals and dissolved carbon dioxide to grow a solid, reef-like structure. (Computer drawing, Christian Kerrigan. February 2009.)

Venice is an ideal site for exploring the theoretical potential of natural computers as an architectural technology, since the watery foundations create the conditions in which matter and energy can freely flow around the site. Indeed, a simple model of this protocell system was tested in tanks of Venetian water on the lagoonside with architecture students from the University of Venice. A simple droplet recipe using a clear, synthetic oil diethyl phenyl phalate (DEPP) of specific density of 1.12 g/cm³ at 20 °C, into which calcium II sulphate crystals were ground into a paste was designed to produce mineralizing 'shells' on contact with the dissolved carbon dioxide in the lagoon water. Currents were generated in the tank through direct agitation to test the robustness of the system, to which the soft mineral bodies successfully proved robust and reassembled, which was an essential attribute for this platform to survive within the Venetian waterways. Infrastructure was also essential in these design-led experiments to optimize the performance of the protocells. The aqueous environment enabled the droplets to exhibit their lifelike qualities, facilitated their movement in the environment and also removed waste products. These early explorations suggest that

protocells may be meaningfully applied within an architectural system with significant impact. However, the system needs further development particularly with identifying an oil carrier system that is not known to be harmful to ecological systems. Yet, through the experimental architectural platform of Future Venice, is possible to imagine how the application of a lifelike technical platform may change the goals of a building. Rather than designing inert sites for the housing of machines, architects may imagine building sites as active interfaces between natural and synthetic systems where the continual flow, catalysis and transformation of materials through a site constitutes the role of an architect. In other words, with the advent of protocell technologies the practice of the built environment could potentially become a life promoting system, not just for humans, but also for entire local ecologies.

9.3 Living Buildings

Since technology is most concentrated in urban locations, the impacts of new technological platforms are likely to be most intensely experienced in our cities. New lifelike technical platforms such as, protocells, may enable buildings to make an origins of life style transition from being inert surfaces, to becoming lively interfaces that can act in our interests. Yet the lifelike properties of dynamic materials can only be supported if infrastructures and media that enable them to thrive are provided. Such elemental infrastructural systems that support the movement of matter namely – air, water, heat, soil - would include for example, breathing systems instead of vents, or circulations rather than drains. This kind of support would enable dynamic materials to even perform work in equivalent ways to machines, such as, producing heat, filtering water or fixing carbon dioxide. Dynamic processes could be designed and housed with architectural ‘organ’ systems that are spatially imagined as hubs of bio/chemical activity, flow and transformation within a site. From a pragmatic perspective, architectural organ systems are likely to be structures such as, aquariums that contain microcellular organisms such as, bacteria and algae, or even smart chemistries, like protocells. Architectural organs would then house and shape the activity within these communities of agents and support them. They could be engineered in ways that rendered them invisible to residents by situating them in under-imagined sites within our buildings such as, under floors or in cavity wall spaces instead of inert insulation. Alternatively, they could also be highly visible such as, in Phillips Microbial home (McGuirk, 2011) – where voluptuously shaped bio processors transform waste products into useful substances within a locally defined ecology. For example, food waste could be turned into biogas and compost to feed new plants and provide energy for the home, or even commercial buildings (Simpson, 2014). Strategically positioned, these architectural organs may be connected into networked activities that could potentially give rise to buildings with discrete physiologies that strengthen the material exchanges within an urban community through networks of metabolic processes that collectively become a life-promoting urban fabric, for human and nonhuman communities.

Yet, such notions are not entirely speculative. The construction-engineering cooperative Arup is currently evaluating facades that house algae to provide energy for buildings in the BIQ (Bio Intelligent Quotient) House project designed for the International Building Association in Hamburg, unveiled in March 2013, see figure 8. These algae facades are essentially aquariums full of microalgae that are fed by sunlight within tall, narrow glass panels through which carbon dioxide is bubbled. As they flourish, the biomass of these microorganisms is syphoned off, dried and combusted to offset energy consumption within the building (Steadman, 2013).



Figure 8: This façade built by Arup for the International Building Association in Hamburg houses green microalgae, which produce biomass from carbon dioxide and sunlight. This product is collected and in turn, is used to create heat for the building. (Image courtesy, Colt International, Arup, SSC GmbH, 2013.)

10. Discussion

Architectural ecologies constitute a design methodology that is fundamentally synthetic, mutable and able to deal with many changing contexts and circumstances – rather like life itself.

In keeping with an experimental architectural practice however, I will not end with a conclusion but instead propose a manifesto. While manifestos traditionally serve as a statement of intent and counterpoint at the start of a project, this particular manifesto aims to actively shape the emerging practice of architectural ecologies by drawing from the projects discussed in this paper and creating opportunities for further design experiments and cross-disciplinary explorations within the emerging field of architectural ecologies. This manifesto therefore, sets out a range of design principles that characterize modern approaches which currently dominate design thinking, which must first be challenged, so that we can establish, extend, develop and evolve – visionary design principles that can meet the complex, changing needs of 21st century architecture.

11. Manifesto for architectural ecologies:

Our 21st century megacities demand a new dynamic architecture that is ceaselessly mutable, fluid and fundamentally promotes the processes of 'life'. Architectural ecologies provide an experimental platform for such possibilities. Yet, they do not spring from pragmatism in which all solutions are already possible but instead, emerge from visionary proposals that carry us into new realms of experience. To generate the conditions in which such an approach may be realized it is necessary to develop an active, experimental architectural design platform through pedagogy and practice. Only then may we transgress the very fundamentals of modern architectural production, namely:

1. **Order** – architectural ecologies seek to reconcile all modalities and establish a commonality of being to secure our long-term, mutual survival. They tirelessly work to transgress established boundaries, transmute existing materialities, erode conventions of form, liquefy Euclidian geometries and usurp existing power inequalities.
2. **Matter** – where Millennial Nature, the nonhuman and the material realm are empowered, not abstracted or reduced, and coauthor our living spaces.
3. **Technology** – in which technological systems do not seek to impose preconceived top-down paradigms of order that seal our futures in a deterministic reality - but facilitate sudden, radical breaks in our experiences through the parallel processing powers of chemistry.
4. **Predictability** – architectural ecologies are exceptional as they are exquisitely sensitive to the their context. Within a practice of architectural ecologies, no two encounters are ever the same.
5. **Interfaces** – architectural ecologies do not seek to thrive in isolation as binary divisions between inside/outside, Nature/artifice, matter/information, or even stay faithful to any one discipline – but ceaselessly synthesize, invent and (re)connect by acknowledging the permeability of the structures and systems that underpin the processes from which 'life' springs.
6. **Scale** – architectural ecologies exist as many manifolds of experience and therefore do not belong to any particular scale. Yet, their character is deeply site specific. At any given set of coordinates in our space-time fabric, they may produce surprising effects conferred by the fundamental strangeness of their fabrics and the laws of quantum physics.
7. **Inertia** – architectural ecologies are not still. They pulsate with the metabolic flow of 'life', which is in tune with their surroundings.

The quest then for 21st century architects, is to imagine, invent and design agile, alternative sustainable urban futures in collaboration with the natural realm and reach escape velocity from the self-destructive environmental pathway that we are currently treading

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