16 Conclusion

And I hear, from your voice, the invisible reasons which make cities live, through which perhaps, once dead, they will come to life again. (Calvino, 1997, p.136)

16.1 Overview

This chapter summarizes the key findings and challenges of my research, which are also used to develop founding principles for the practice of vibrant architecture.

16.2 The Agency of Matter

The transformative technological potential of this physical realm is possible through the significant contributions made by non-humans, such as molecular forces, that have invested in the infrastructure for our existence. Vibrant architecture experimentally investigates how to design along with these agents in more environmentally positive ways (see Fig. 16.1).

The agency of our material realm is distributed across the actions of many different actants that are an intrinsic part of our urban communities – from catalytic surfaces to viruses, microbes, mycelial networks, flocks of pigeons, tumbling plastic wrappers, clouds of fungal spores and wandering, thin soils. All these bodies stretch from the subatomic realm to the megascale, entangling us within many parallel

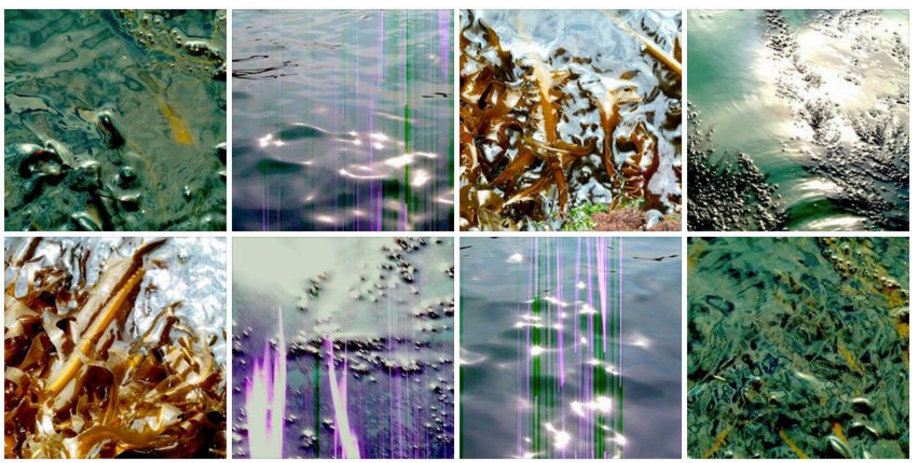

Figure 16.1: Non-human actants inhabit the shores of Venice and are continually (re)defining its boundaries. Photographs and collage, Rachel Armstrong, August 2012.

realities that intersect with our architectural design interventions. Indeed, we may begin to value matter differently if we acknowledge the diverse material communities that have collaborated to create the conditions for our survival. By consciously appreciating the enormity of these collective endeavours and the vast investment made by non-humans in our own culture, we may be more inclined to build on, rather than destroy, these relationships. Our modern industrial worldview that shapes the way we imagine our living spaces rests on object-centred canons that narrow the possibilities for architectural design practice down into object-centred, geometric plots and adopts an almost exclusively anthropocentric perspective. This illusion of architectural certainty is being assaulted by the increasing turbulence within natural systems (*Bloomberg*, not dated; Dolnick, 2011; NBC News, 2012; *Telegraph*, 2013), and the idea that we are 'in control' of our environment is melting along with our polar ice caps (see Fig. 16.2).

Yet, if we are to develop more environmentally compatible approaches, our assumptions about the material realm require significant deconstruction – and reconstruction to propose alternatives, by constructing manifestos and populating these concepts with many new 'species' of architecture. Radical new proposals are needed to catalyse this punctuated equilibrium in architectural design evolution – where new features suddenly appear and reach escape velocity from what has gone before to carve out new territories, which also requires new ways of thinking. These propositions also need to be grounded in a technological reality so that they may be explored and realized.

Vibrant architecture draws from the technological qualities of Millennial Nature. Matter has never been predictable or obedient. We have simply learned to understand it this way through Enlightenment perspectives. My proposal is that, by appreciating the potency and profound investment that non-human agents have made and continue to contribute to our existence, it may be possible to challenge entrenched architectural mores and practices; by appreciating the liveliness of the material realm, so that production of architecture may be regarded as more than the production of a finely crafted object or building, but the beginnings of developing a site of activity through

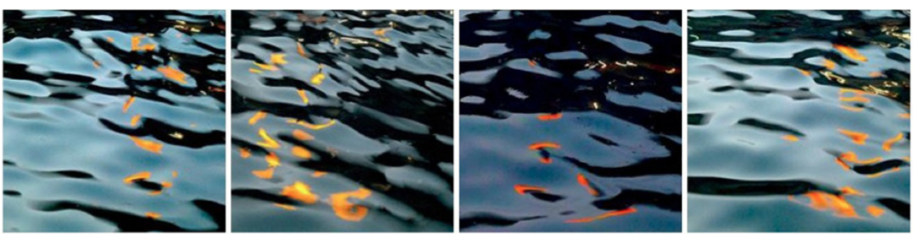

Figure 16.2: Reflections at dusk on the Grand Canal in Venice. Photographs and collage, Rachel Armstrong, August 2012.

which many ecological events can be orchestrated through material relationships (see Fig. 16.3). Yet, this approach requires a different kind of thinking that can apprehend the complexity, connectivity, fluidity and multi-scalar nature of working with innately empowered bodies. Vibrant matter resists formal classification, as it is a shape-shifter, potent transformer and production platform that operates independently of human intent through the coordinated action of assemblages. However, although vibrant matter exhibits varying degrees of autonomy, it is not anti-human and may work alongside us as codesigners of our living spaces.

Yet, at the human and, therefore, architectural scale, the materialist view of vibrant matter[80] provides architects with access to materials with lifelike qualities. Consequently, my research set out to explore a range of materials that visibly expressed these qualities (Bennett, 2011). A range of complex chemistries at far from equilibrium states were identified as appropriate models that could experimentally

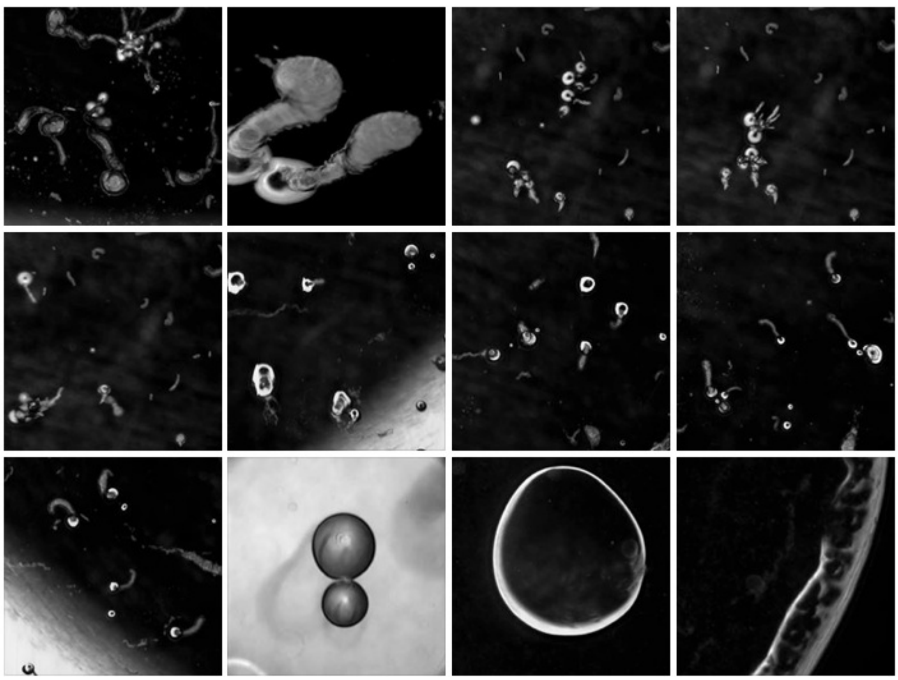

Figure 16.3: Countless populations of non-human agents may be shaped through ELT to produce new kinds of architectures. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

80 A materialist view of vibrant matter regards the effects of materials as originating from within their substance as a function of their quantum nature and does not look to vitalism, ephemeral forces or perceptual influences to account for their ability to act.

demonstrate the properties of vibrant matter such as Bütschli droplets, Liesegang diffusion/precipitation reactions and Traube cells, which were used as model systems to interrogate and explore the implications for working with vibrant matter in architectural design practice (see Fig. 16.4). Chemistry was used as an embodied language, which operated as a combined software and hardware platform, which could potentially negotiate with the untapped potential of various vibrant matter species. Such a discourse was possible by applying morphological computing techniques to persuade lively substances to ally with the human cause through the production of assemblages as a creative negotiation between different 'bodies' (Adamatzky et al, 2013).

Based on observations made through experiments, models and prototypes, it became evident that vibrant matter was more than a design substrate that could be modified by internal and external interventions, but also constituted an emerging

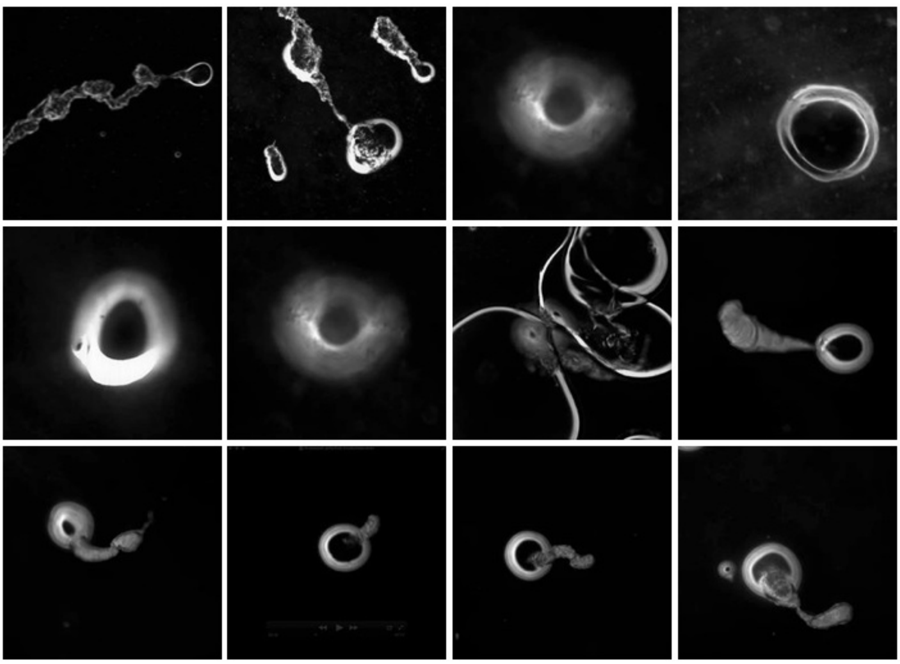

Figure 16.4: Bütschli dynamic droplets served as a model system to investigate the effects of 'vibrant' matter in an experimental context by possessing agency and exhibiting Bennett's criteria (Bennett, 2011) of slowness, porosity and inorganic sympathy. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

technological platform, or ELT, whose outputs could be navigated, shaped, and communicated through acts of architectural design.

At an architectural scale, when vibrant matter is entangled and shaped within our living spaces, it produces ‘vibrant architecture’, which is more than a container, or ‘machine for living in’ (Gallagher, 2001; Le Corbusier, 2007, p.158), but embodies lifelike processes that codesign our spaces, and ultimately helps shape our evolution. Vibrant architecture may seamlessly operate within mechanical and process-led worldviews and can therefore be viewed as both an object and a process. Yet, fundamentally, it is a transformer, which breaks down the ontological barriers that set objects and systems in opposition, by horizontally coupling them together through the production of assemblages and synthesizing oceanic ontologies (see Fig. 16.5). This increases their combined effects of heterogeneous agents, which may bring about radical transformation within these newly connected systems to produce something entirely new. This material convergence provides a new production platform whose operations are shaped by spatial programs and are amplified through the interactions of assemblages across many scales.

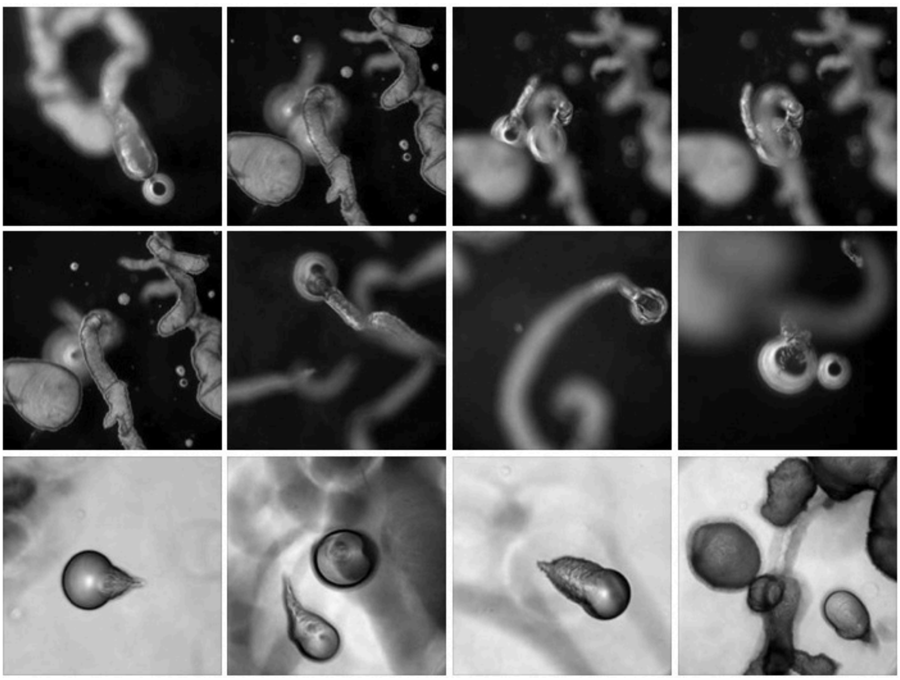

Figure 16.5: This micrograph collage depicts Bütschli droplets responding to internal and external conditions to amplify and scale up their effects. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

Congregating assemblages of vibrant matter may give rise to vibrant architectures and cities, but, uncared for, equally produce our rubbish tips (Bennett, 2010, p.6) and great oceanic garbage patches that ooze noxious substances into the environment. The lively bodies of these assemblages spring from the multitudinous, seamless entanglements of humans and non-human codesigners as fundamental soil-like systems. They build fertile, post-natural landscapes, which are rich with lively new material possibilities and may even shape human development, so that our continued survival is also beneficial for our non-human codesigners.

In this way, vibrant architecture is more than a new production platform that can shape our living spaces but proposes that architectural design may forge a qualitatively new relationship with Nature. Yet, vibrant architecture does not inhabit the incarcerated shroud of Old Nature (Van Mensvoort and Grievink, 2012) and nor does it stand against humanity as anti-modern Nature (Koolhaas, not dated). It does not embody neo-environmentalism that views the material world as a robust 'standing reserve' (Heidegger, 1993), or acts as little 'soft machinery' (Spiller, 2007, pp.202–224; Burroughs, 1961) that is destined for assimilation within industrial paradigms. Rather, vibrant architecture proposes a relationship with a new kind of Millennial Nature that incessantly forges relationships between many heterogeneous bodies. Indeed, it challenges the conventional taxonomic definitions of life, where Nature itself is not a distinct set of objects, but a technological substrate and connecting substance that may be modified and transformed by the actions of many actants.

Millennial Nature does not reside in the wilderness, the countryside or on the pretty rooftops of tall buildings, but infiltrates our urban environments. Rather than being a wan damsel in distress, awaiting rescue from the ravages of industrialization, she has metamorphosed alongside her legions of antibiotic-resistant microbes into something stranger, more substantial and infinitely more subversive. Millennial Nature confronts us with her raw, culturally unedited substance, which heaves open the tops of barely-buried garbage icebergs, oozes from guano-rich crevices that melt building fabrics and splits the paving slabs of walkways with her exploding weeds. Millennial Nature smothers us with her vitality at every twist and turn of the urban landscape and bleeds into the spaces beyond – yet we choose to edit out her presence and remain oblivious to her staggering materiality (see Fig. 16.6).

Smitten by cruel, cultural nostalgia (Morton, 2007, pp.4–5), we refuse to accept that Nature is maturing into a new materiality that fits her fuller 21st century figure. Instead, we long for those bygone days of imagined bucolic perfection, so we corset her up behind façades of polished stone and plump up her sagging tissues with obedient lawns, as if we were conducting cosmetic surgery.[81] Yet no matter how much we try to avoid her grotesquery – by burying her in great holes carved in the earth, or purging

81 Morton likens our admiration of Nature to what patriarchy does for the female figure by putting it 'on a pedestal and admiring it from afar' (Morton, 2007, pp.4–5).

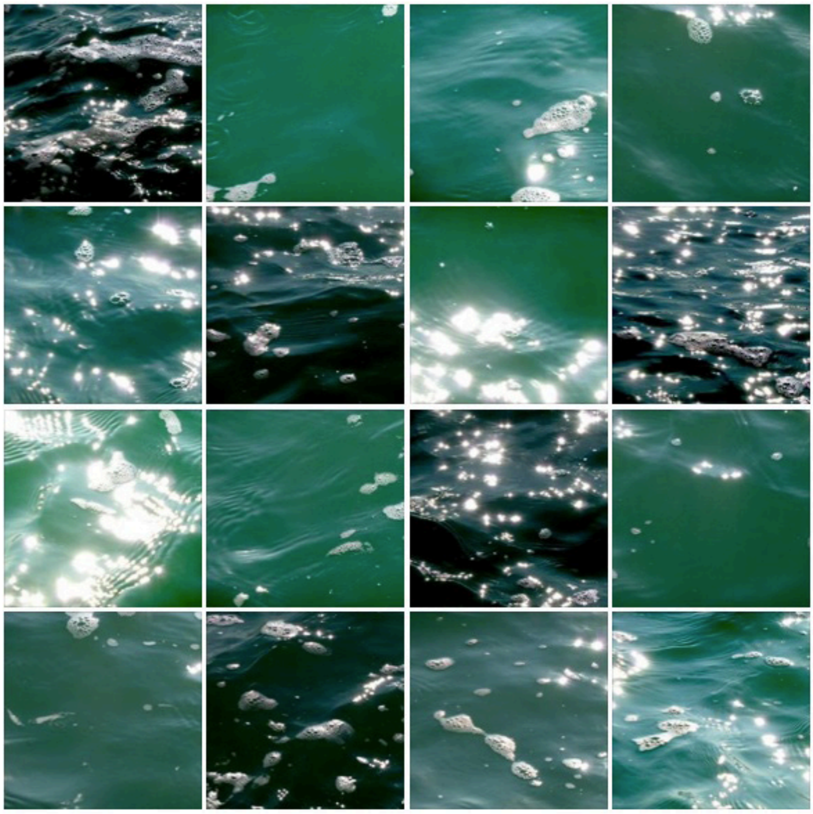

Figure 16.6: Non-human actants may codesign our spaces through assemblage formation and transformation of matter. Photographs and collage, Rachel Armstrong, August 2012.

her filth from our cities through our sewers into our acidifying seas – our living spaces are nevertheless crawling with her tissues and she continues to thrive. Indeed, she lies – barely chemically 'breathing' – in metabolic suspension in garbage graveyards where she is decoupled from networks of biospherically essential exchanges, which may have sustained her corpulence or enabled her rebirth through the revitalizing production of compost. Yet, like Tarantino's Bride,[82] Millennial Nature defies the odds against her survival and resurfaces from her untimely grave to exert her revenge by leaking carcinogens and volatile gases into our urban environments (Canada.com, 2007). These acts of resurrection are nothing less than magnificent, as she gnaws the Earth with pitiless sinkholes, advances algal blooms in our seas and dazzles our skies

82 Here, I am referring to Beatrix Kiddo, or 'The Bride', who is the lead female character in Kill Bill Vol. 2 by Quentin Tarantino (2004) that claws her way out of a grave to seek revenge on her enemies.

with rainbow-brilliant, polluted sunsets, which continue to invoke awe in those who may have feared that her splendour had somehow faded as she (re)negotiates her survival (see Fig. 16.7).

Figure 16.7: Assemblages of actants negotiate the harsh environment of the Venetian shoreline and flourish against the tempestuous odds. Photographs and collage, Rachel Armstrong, August 2012.

16.3 A Recipe for Vibrant Architecture: An Experimental Approach

My conclusions are informed by critical theoretical reflection and speculative inquiry and fuelled by architectural design questions based in experimental research. This has added depth and complexity to my investigations and enabled the properties of vibrant matter to be tested in a design context, through the production of drawings, models and project work.

Vibrant matter was explored as a real substrate for architectural design practice using dynamic chemistries. A range of systems were developed in a design context, such as the Traube cell and Liesegang rings, which offered a combined production platform that could be manipulated using morphological computing techniques. However, the mainstay of my experimental work was conducted using Bütschli droplets as a demonstrator platform, which were characterized and explored through a series of experiments, models and projects (see Fig. 16.8) that interrogated and portrayed the nature of such lively materials, using a variety of methods and contexts to reveal a set of principles for the production of vibrant architecture.

While the identified practical principles are most readily applied to systems at far from equilibrium states, the design considerations also still apply to materials at equilibrium, since, as Kauffman notes, the idea of classical equilibrium is a relative condition, not an absolute one (Kauffman, 2008, p.125). Architects may, therefore, decide whether they are dealing with relative equilibrium or non-equilibrium conditions, according to the scale at which they are working and the particular design context. Applications of this form of design thinking may be considered as ecologically compatible practices, since, over the last few decades, environmental behaviours have been recognized as working in accordance with the principles of systems theory (Von Bertalanffy, 1950; Willis, 1997), which also underpins the operational principles of materials at far from equilibrium states (Prigogine, 1997) (see Fig. 16.9).

My research aimed to establish whether it was possible to develop a 21st century architectural design practice that deals directly with material complexity whose 'object status' is not contravened, but accepted and extended into the territory of dynamic systems. By elevating the status of the material world and attributing it status

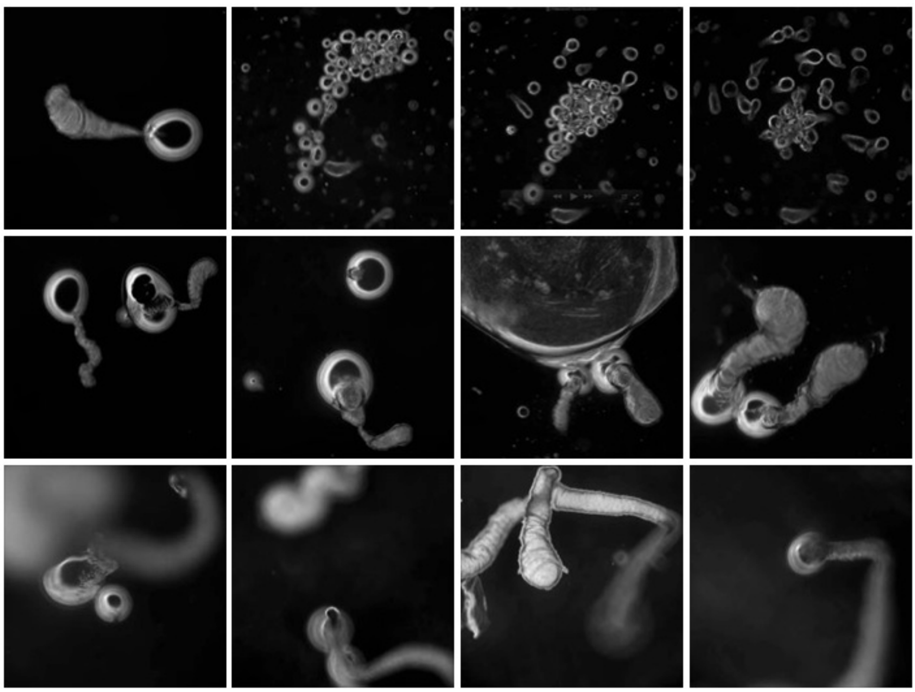

Figure 16.8: Bütschli droplets provided a dynamic model experimental system through which 'vibrant' matter could be explored as a material at far from equilibrium and potentially applied within an architectural design context. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

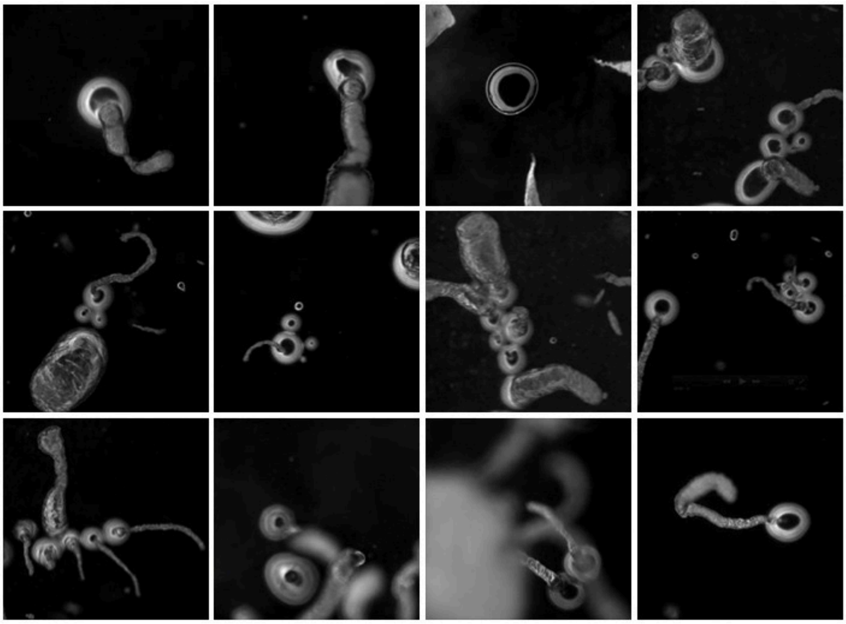

Figure 16.9: The Bütschli system possesses unique poetics and aesthetics at the microscale, with some homologies with natural systems. The design challenge was to translate these possibilities to the architectural scale. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

within the design process, it may be possible to draw attention to the codesignership of our living spaces produced by agencies that are not under our instruction – for example, by growing lively materials that may continually adapt to their environment (Rowlinson, 2012). This does not mean that there is no role for the human designer in shaping our living spaces, but asks architects to think differently about how materials, infrastructures and technologies that are used in architectural production respond to spatial programs as acts of codesign in the production of living spaces (see Fig. 16.10).

16.4 Embodying Complexity

Complex materials are generally conservative in their performance but operate within definable limits of predictability (see Fig. 16.11).

My research endeavoured to directly harness their potency and capacity as a codesigner of architectural systems. I have used informed speculation, grounded in experimental observation, to explore possible outcomes of design tactics and architectural programs where overlapping knowledge fields and methods may synthesize specific approaches that can deal with probabilities, rather than fixed

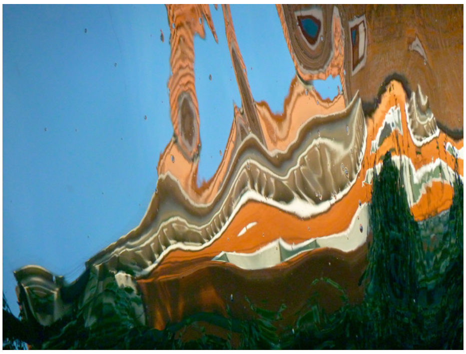

Figure 16.10: These reflections hint at the possibility of harnessing the power of the material realm to generate novel approaches in architectural design. Photograph, Rachel Armstrong, August 2012.

Figure 16.11: Venetian canal reflections offer an interface through which it is possible to see time and matter evolving in a dynamic material system. Photographs and collage, Rachel Armstrong, August 2012.

products. Working with vibrant matter and ELT requires designers to surrender five pillars of architectural certainty, which are summarized in Table 16.1.

Table 16.1: Architectural pillars of certainty

Pillar of certainty	Limitation	Alternative
Predetermined designs	Hermetic approaches and practices that resist change	21st century architectural design is an open, collaborative process that works in partnership with and is informed by other disciplines, so it remains responsive to changing needs, ideas and contexts that are not contained within predetermined designs but are fashioned through continual, iterative exchanges
Sole authorship	Hierarchical, centralized control systems that are executed according to a centralized plan reduce the complexity of possible material responses to the spatial programs of a site	As codesigners of systems, architects may work in collaboration with other humans and non-human agents through processes that do not invoke hierarchies of order but forge mutual relationships between many heterogeneous agents. These can respond to complex challenges through a form of actant-led ‘crowdsourcing’ of challenges where morphological computational decisions are made by heterogeneous groups of actants in a distributed and cooperative way
Discrete boundaries	Impermeable barriers limit the possibility of exchange between material agents and prevent environmental responsiveness	Porous interfaces enable the collective action-organizing ‘hubs’ of activity that may respond to spatial programs beyond the life of an architect
Incremental research goals	Risk of redundancy with the advent of disruptive events and technologies	21st century architecture is not about tinkering around the edges of what already exists but has a moral obligation to future architects and the public through ambitious, visionary thinking
Completion	Does not enable the possibility of change with time	Ideas as well as solutions change and are in constant evolution. Architecture is never truly finished but is an open process that is never fully resolved. Buildings continually contribute to biospherical processes and may be adapted by and assimilated within future architectures. They may also be recycled and transformed into other systems such as soil

16.5 Site-specific Exploration of an Emerging Technological Platform

While laboratory findings provided essential information about the possibilities of ELT, prototype experiments in the site-specific context of Venice created a set of conditions that focused development of the emergent technological platform within an architectural context. Specific questions were raised about the feasibility of designing a dynamic droplet system that could potentially 'grow' an artificial limestone reef under the darkened foundations of the city by developing a basic prototype droplet system that could model some of the proposed effects. Experimental findings were iteratively combined with speculative approaches that used ELT to develop the prospect of enabling Venice to literally fend for itself in an environmental struggle for survival. Using Stengers' notion of 'an ecology of practices' (Stengers, 2000), it was possible to reflect on the kinds of conditions that would enable such a technology to draw raw materials from the lagoon through many acts of codesign and work in concert with humans and the marine wildlife to produce a reef-like architecture (see Fig. 16.12).

Figure 16.12: Mineral accretions forged by biological and chemical systems spontaneously form around Venice's shoreline. Photograph, Rachel Armstrong, August 2012.

16.6 Scaling ELT to Urban Dimensions

The idea of soils as architectural-scale bodies was developed in the context of vibrant cities by considering them to be technological expressions of vibrant matter, which are forged by an entanglement of biological and chemical agencies. Soils are metabolically active and enable the free flow of elemental systems through them, such as air, water, heat and matter. Applying the technology of soils within buildings as entangled assemblages and composites of vibrant matter, which do not slavishly mimic biological processes, but interpret their environments through morphological computing processes, could potentially transform and recycle resources to perform useful work such as the production of heat and filtering wastewater. The by-products of these metabolic processes could also potentially produce 'urban' composts as a valuable resource to increase the fertility of the urban environment. For example, vibrant cities may produce native, not transplanted, soil systems that enable metropolitan greenery to flourish (Armstrong, 2013a) (see Fig. 16.13).

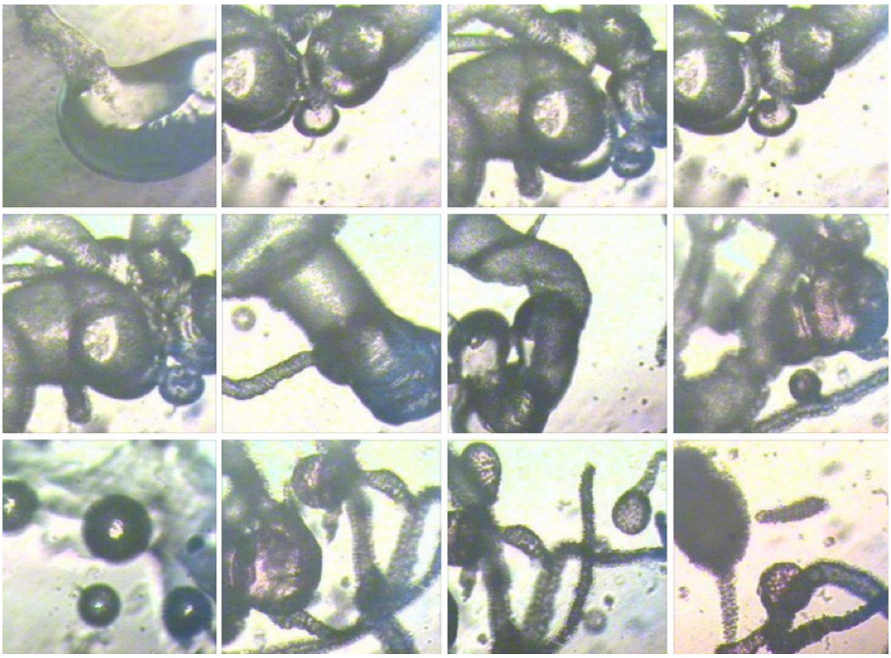

Figure 16.13: Soils may be regarded as a complex chemical technology capable of many acts of transformation. Micrographs and collage, magnification 4×, Rachel Armstrong, August 2012.

16.7 Speculative Narratives as a Means of Exploring Innovation Space

During my research, I composed a series of speculative narratives, which explored topics ranging from synthesizing lifelike agents from chemistry in a laboratory environment to imagining cities built upon the principles of vibrant matter. Each of these design propositions was regarded as an extended hypothesis that was in keeping with the exploratory nature of my research and the kinds of materials and approaches adopted in my investigations. Developing these scenarios opened up new spaces for reflection on the experimental systems, emerging practices, materials and technologies that I was working with, which are not formally available outside of a laboratory setting and whose outcomes had not already been established and/or could not easily be predicted (see Fig. 16.14). These narratives served as instruments for reflecting possibilities back into the real systems with which I was working, and enabled me to make decisions about my research. For example, the relationship between vibrant matter and morphological computing in an architectural context was not sufficiently mature to offer formal approaches to the research proposals.

Speculative propositions, however, were not made in ignorance of emergent systems but were informed by having a working understanding of vibrant matter in a design context, identified model systems, made observational studies and conducted chemical experiments. These first-hand experiences enabled me to work iteratively between informed speculation and practical engagement, which enabled further reflection, design and development of ongoing research questions. These possibilities helped further understanding and development of the project by reflecting on the aesthetic qualities of the project, as well as engaging with the dynamics of the accretion process in ways that would not be testable through real-world experiments. Although speculative approaches do not advance development of the technology towards its implementation, they have greatly assisted in the progression of research ideas and will be used to inform further experiments, models and prototypes.

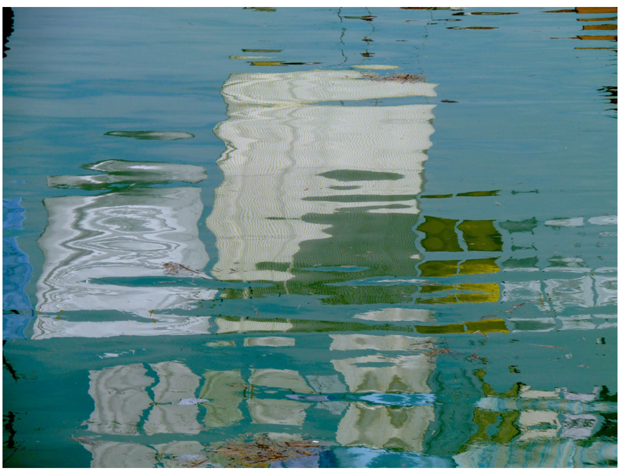

Figure 16.14: In this photograph, washing on a line is transformed by the active surface of the canal water into discrete, vibrant architectural territories. Photograph, Rachel Armstrong, August 2012.

16.8 Manifesto for Vibrant Architecture

This manifesto addresses the strangeness of the material realm and proposes new relationships between humans and non-humans that do not advocate the triumph of one set of principles over another. Despite the inevitable polemics of writing a manifesto, I aimed to draw attention to the transformative powers of the material world so that it was possible to appreciate its codesignership in the production of living spaces (see Fig. 16.15). A manifesto for vibrant architecture therefore not only summarizes my research findings as a set of design propositions, but also identifies opportunities within architectural practice for new spatial programs and design tactics that may form the basis of further research.

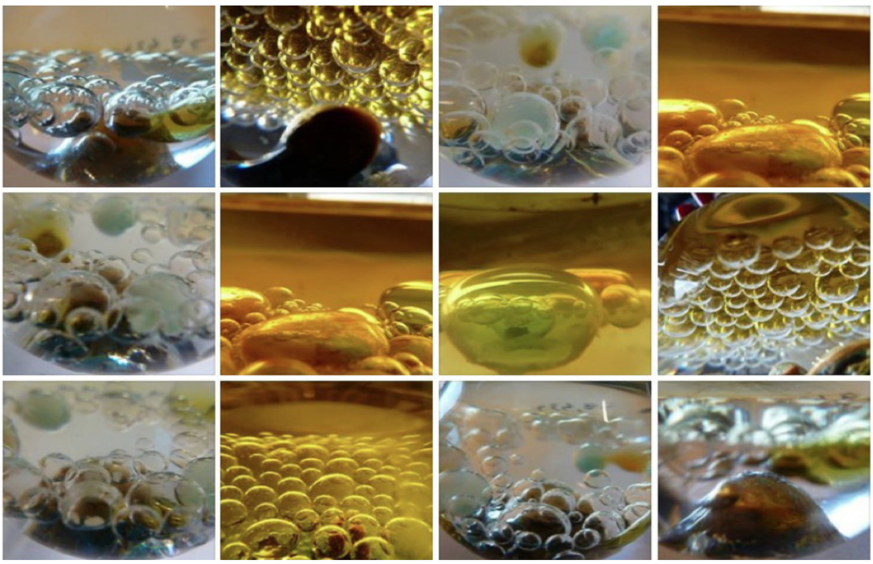

Figure 16.15: Bütschli droplets provided a model system for a manifesto of 'vibrant' matter. Photographs and collage, Rachel Armstrong, February 2009.

16.9 Designing with Vibrant Matter

This section reviews the major research findings, which explore the challenges of working with complex, embodied systems. These are:
— Design with probability
— Process as material
— Design with lifelike systems

16.9.1 Design with Probability

Designing with probability means shaping the environment and context of a system so that it is likely to provoke an event, rather than focusing on a single end point that predetermines the outcome of the system. My research established a set of principles for dealing with non-deterministic systems by, firstly, creating the context in which this kind of approach could be imagined. Terms derived from process philosophy that invoked ideas about relationships, flows, networks, systems, agents, actants, and assemblages were explored as a way of creating the conceptual context for probabilistic design events. Process-based terminology evokes the kinds of possibilities that may be expected within limits of definable probability. Probabilistic design is an inherently creative way of working, where materials creatively participate in the development of spatial programs as codesigners of the system. The production platform through which probabilistic design is realized is based on the production of assemblages. These are inherently flexible systems that deal with matter at non-equilibrium states and are extremely responsive to environmental changes. Their outputs may be shaped by using parallel computing processes to produce sustained material outputs that (even briefly) resist entropic decay towards inertia. A comparison between probabilistic and deterministic design paradigms is summarized in Table 16.2.

The implications for using materials at non-equilibrium are that they challenge deterministic principles of design and work with probabilities. Indeed, the frameworks that underpin their development operate according to the same organizational principles as Nature. Rather than suffering the wear and tear of object-centred designs in the environment, they are instead prone to derive sustenance from the continual transfer of material and may adapt to persistent patterns of exchange. Alternatively, they may transform as internal and external circumstances change. This challenges the way that architecture is represented, planned and executed and requires programmatic approaches that can deal with probability, which resist confinement within the complexity of non-geometric spaces and deal with changes in performance of the various systems and actants with time. For example, Neil Spiller and Perry Kulper propose drawing tactics that embrace many dimensions of reality – both empirical and subjective – to explore a new, probabilistic, fabric of reality (Spiller, 2011). Alternatively, the Hylozoic Ground chemistries are not representations but the ‘things in themselves’ that mediate change in their surroundings and are not represented, but developed *in situ*, as they are only truly ‘known’ when they are constructed (Armstrong and Beesley, 2011).

Table 16.2: Comparing design in probabilistic and deterministic paradigms

Principle	Probability	Determinism
Language	Process-led. Imagined as potent fields of interactivity that may give rise to unique events	Object-oriented. Described as ordered hierarchies and sequences
Metaphors	Complex, alchemical and open to multiple interpretations	Simple, aim to reduce ambiguity and distil concepts into discrete elements
Programming	Parallel	Series
Ontology	Oceanic ontology, which is changeable and context-sensitive (Lee, 2011)	Hierarchical and fixed relationships
Limits	Relativistic and provoke creativity	Absolute and inhibiting
Identity	Fluid, multiple, parallel, transgressive and transmutating	Singular
Time	Directional, acts to shape events in complex and radically creative ways. Not reversible	Reversible
Relationship with Nature	Works synergistically with the relentlessly material and continually reforming systems of Millennial Nature	Reinforces binary divisions of Old Nature and establishes oppositional stances
Taxonomy	Convergent and alchemical	Divergent, represented through tree-like branching structures
Epistemology	Evolving, contextualised and perpetually in transition	Context-sensitive, constrained by perceptual and linguistic influences (Jablonka and Lamb, 2006). Potentially 'post-epistemological' or unclassifiable according to traditional modes of classification (Latour, 2013)

16.9.2 Process As Material

> *The role of the architect here … is not so much to design a building or city as to catalyse them: to act that they may evolve.* (Pask, 1995, p.7)

Process-led materials exist at non-equilibrium states and may produce structures that change with time. For example, modified Bütschli droplets are roughly spherical but gradually produce crystals that alter the shape of their oil/water interface container. Yet matter at non-equilibrium states has similar requirements to living systems, which thrive in open, resource-rich environments and require elemental systems that enable the free flow of matter and the removal of waste. As such, designing with process-led materials requires different conditions than those for making objects. A range of factors that shape design decisions are listed in Table 16.3.

Table 16.3: Designing with process as material

Principle	Observation	Design Decision	Example
Open system	Closed systems reach equilibrium states	Identify abundant resources and map them. The flow of matter through the system influences the way that processes evolve and will inform oceanic ontologies, e.g. exchanges between the actants in the Venetian lagoon such as light, marine organisms, minerals and carbon dioxide will shape the character of mineral shells in protopearls	Bütschli droplets are expected to remain dynamic longer in an open system such as the Venetian lagoon than in the relatively closed Hylozoic Ground flasks, which have much more limited surface area for exchange with their surroundings
Abundance	Processes are enabled in sites with plentiful resources and restricted by scarcity	Maximize surface area available for exchange e.g. using effusive, convoluted surfaces rather than smooth ones, to enable circulation and transfer of matter to prolong processes, such as mineralization in Mother Shipton's Cave, where a continual flow of heavily mineralized waters through spongy foam and fabric feed crystal growth	Copper ion availability limits Traube cell growth in solution. When this limitation is removed the typical 'cell' continues to grow
Context	Operates within definable limits. Extremely sensitivity to environmental conditions. Performance is site-specific and unique	Environmental conditions may need to be designed or manipulated to enhance material performance, e.g. Traube cell growth can be extended in a biopolymer rich environment, which allows water to enter into the system more slowly, provide support to fragile membranes and produces a different structure (narrow rather than broad) to that grown in an aqueous environment	Protopearls in the Vibrant Venice project form crystals under alkaline conditions and mineralize in the presence of silica salts
Metabolism	Sets of chemical exchanges and interactions produce energy and change within a system	'Messy' combinations of interacting chemistries may produce more surprising and persistent outcomes than carefully measured relationships, e.g. complex exchanges between a range of different salts in modified Bütschli droplets in the incubator flasks produced a variety of interior structures	Metabolisms are most effective when an environmental component is incorporated into chemical exchanges, e.g. protopearls use water as source of carbon dioxide and minerals

Continued **Table 16.3:** Designing with process as material

Principle	Observation	Design Decision	Example
Vectors	Breaking symmetry in chemical systems induced polarity and directionality and results in physical forces, which create observable effects, e.g. propulsion, growth, expansion	Establishing a clear context and mapping environmental conditions may help designers influence the rate of change and direction of movement within a dynamic material system. The techniques that may achieve these outcomes are more similar to 'gardening' than engineering a machine	The rate and direction of change in dynamic systems is dependent on the flow, environment and texture of the material, e.g. Traube cell growth on bioscaffolding can be extended under the influence of gravity
Dissipation	Materials not only take in energy and matter but also release it during 'organizing' phases that take place when systems are far from equilibrium	Changing the condition of the medium, environment or the body of the agent, can optimize conditions for the probable emergence of dissipative structures. The vigorous material exchanges in dissipative systems are pluripotent and early stage disturbances shape subsequent events as in the production of osmotic structures by Bütschli droplets	Bütschli droplets exist as dissipative high-energy 'shell' structures that release energy into the medium, which contributes to the emergence of organized droplet structures
Medium	Processes require media that enable movement such as gaseous or wet conditions	Using a combination of media and materials (like developing layers of embryonic tissue) enables process-led systems to develop a range of outputs and therefore diversify audience experiences, e.g. Hylozoic Ground chemistries are entangled with a range of dynamic media such as liquids and gases that enable them to change and grow with time	Intensely organizing systems are possible in gaseous media, such as the cloud installation by Berndnaut Smilde (Design Boom, 2012) and in liquid media, such as the Hylozoic Ground chemistries
Quality	Process-led materials are soft and dynamic	Oceanic ontologies establish the range of material possibilities that may be processes by a particular architectural program for a specific site and conditions, such as in the Bütschli system	Bütschli droplets exist in a number of changing, variable forms and leave soft, crystalline 'osmotic' residues

Continued Table 16.3: Designing with process as material

Principle	Observation	Design Decision	Example
Spatiality	Agents form intimate connections with the surroundings through the production of assemblages. These participating bodies confer process-led materials with a rich dynamic and undulating spatiality	Novelty may be induced by overlapping spatial programs, e.g. Liesegang rings are produced by periodic spatial interactions between salt solutions and alkalis, which are further spatially separated under gravity to produce banded formations. Banding does not happen without spatial distribution of the participating chemistries	Using matrices can produce qualitatively new events and structures, e.g. biopolymers, to separate chemistries and prevent them from being homogeneously mixed, such as in the Liesegang ring reaction
Time	Processes change with time, which is source of creativity in the system	Time-based interventions may increase the likelihood of specific events in overlapping spatial programs, e.g. organic solvents are attractants during the early stages in the Bütschli droplet system (chaotic and organizing) but have little effect on later stages (quiescent), so transformative interventions need to be designed to occur at an early stage in the development of the system	Dynamic chemistries such as Bütschli droplets are time-sensitive in their operations, being more plastic early on in their operations when they are furthest from entropic equilibrium
Transformation	Materials constantly change in response to internal and external cues until they reach equilibrium	Dynamic materials are indicators of change. Process-led materials may create different products, which are influenced by many variables and factors. These changes can be recorded, e.g. as material traces or drawings that depict chemical information landscapes that are otherwise invisible to the unaided eye. Notably, Bütschli droplets may shed a range of skins that may be regarded as 'wet' drawings	Bütschli droplets exhibit different forms and behaviours during their organizing phase

Continued Table 16.3: Designing with process as material

Principle	Observation	Design Decision	Example
Decay	Dynamic materials approach entropic equilibrium as environments and agents become homogenous	Increasing resource availability or changing environmental conditions may prolong process-led systems. For example, stirred reactors may increase the longevity of the Belosov–Zhabotinsky reaction (Hsu, Mou and Lee, 1994). However, decay in process-led systems is inevitable and designers need to decide what to do when their dynamic system is no longer able to self-repair, or is no longer viable (Woods, 2012b). For example, aging and decay may be an intended form of obsolescence that serves as the foundations for other, more vigorous systems (like a coral reef or stromatolite)	The 'werewolf' transition in the Bütschli droplet system is an indicator of entropic decay and signifies a complex, phased transition towards inertia that occurs between the organizing and quiescent phases of Bütschli droplets. Droplets become agitated and produce large amounts of residue before becoming inert

Process-led, design decisions may be informed by elevating the status of matter in the system and incorporating non-equilibrium materials into spatial programs. This provides architects with the possibility of developing and working with a whole new range of materials, technologies and construction processes in the production of space. For example, living spaces may have 'metabolic' functions that are shaped by soft materials such as algae and bacteria that are able to process water, waste food and packaging in community spaces, or within spandrels (Gould and Lewontin, 1979) in our homes. These unconventional spaces are akin to Matta-Clark's 'Fake Estates' – a project where the artist acquired a number of miniscule plots of land auctioned off by the city of New York that were of redundant utility (Kroessler, Richard and Finkelpearl, 2005). In other words, the existence of these slivers of no-man's land was determined by factors other than formal architectural programs being distributed; fragmented spaces with deregulated spatial characteristics. Such sites are potential hosts for urban physiologies that constitute an extended notion of spatiality, through material networks, metabolic linkages, synthetic ecologies and post-natural fabrics within our cities. These subversive, distributed spaces are sites of programmatic (re) invention and nascent fertility that may ultimately enable societies not just to be consumers, but also producers of their spaces. As codesigners in the production of space, living architects may cultivate material, infrastructural, technological, social and cultural relationships and use soft control design tactics where appropriate to nurture and encourage fertility in the development of urban ecologies and post-natural landscapes.

16.9.3 Design Characteristics of Lifelike Systems

My research aims to outline a toolset of concepts and approaches that may help designers work with matter in more vibrant, lifelike ways. Experimental work produced during my research established that vibrant matter:

- Possesses agency
- Programmable with morphological computing techniques
- Exhibits co-authorship in our environments
- Coherently operates across many scales that include the architectural realm

Unlike digital technologies, lifelike systems do not need every possible outcome to have been anticipated before they deal with a challenge, but may find ways to resolve them using real-time parallel processing. This does not mean that lifelike systems are infallible – if they do not produce a solution, they may 'crash' and become inert. Yet, the history of 'life' is characterized by continual losses and extinctions of material solutions. Those that are successful become increasingly adapted to the kind of challenges found within a particular environment or niche. Biologists refer to this process as evolution. Although design principles for working with biological systems and lifelike systems are similar, there are important differences that relate to the value placed on their respective performances. Table 16.4 summarizes characteristics of lifelike materials which have been derived from my experimental work and the expectations that designers may have of them.

Working with lifelike materials implies that architects are codesigners of spatial systems and, therefore, require design tactics, materials, infrastructures and technologies that help to negotiate the complex and often contradictory relationships that emerge continually in living systems. Vibrant architecture requires human participation and engagement if it is to be shaped and developed towards a specific design outcome. While managing these networks is energy intensive, it is likely that at least a degree of the infrastructural regulation within living architectures may be performed by computer-generated processes through microfluidics chips. These can regulate infrastructural performance in biological/chemical/mechanical systems, yet the degrees of freedom that escape mechanization create opportunities for personalizing synthetic ecologies so they have individual characters. Such communities require a shared language that can grow and develop accordingly as the post-natural fabrics that were forged through their intimate interactions evolve.

16.10 Vibrant Matter as Technology

Vibrant matter may provide a new technological platform, or ELT, when physical agents are combined with morphological computing techniques. The system may be orchestrated by designers using a chemistry-based language that interprets spatial

Table 16.4: Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Agency	Acts autonomously on the environment to exert effects that influence human interactions	Lifelike materials are empowered and produce a variety of different effects that may change with time, e.g. phase transition behaviours of Bütschli droplets	Dynamic droplets can move around their environment, sense it, interact with other agents and participate in population scale behaviours
Uniqueness	Lifelike materials are functions of their internal composition, environment, context and relationships	Designers may influence the outputs of lifelike materials by changing internal and external conditions in the system	No two Bütschli droplets are alike
Programmable	Morphological computing techniques can chemically and physically shape events	Designers may reveal environmental details that are invisible to human senses and record them using lifelike systems, such as Bütschli droplet drawings	Modified Bütschli droplets in space-constrained environments may produce Turing bands
Anthropocentrism	Lifelike materials resist anthropocentrism	Designers may work inclusively with 'ecologies of design' (Stengers, 2000) so human and non-human agents can work alongside each other without hierarchies of order	An artificial limestone-like reef may be 'grown' under Vibrant Venice through the action of multiple non-human agents, e.g. 'smart' droplets, marine ecologies and tidal flow
Design method	Living materials deal with persistent change and evolving outcomes by acting as codesigners of these systems	Architects need to manage the difficult relationships between communities of actants that operate according to artisan-led, bespoke, distributed, decentralized processes that may be shaped by humans through 'gardening-like' processes, such as Explora Biotech's 'husbandry' of the Bütschli system over the duration of the Hylozoic Ground installation.	Architectures are grown and change with time and according to their context, such as Hylozoic Ground chemistries

Continued **Table 16.4:** Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Combined platform	Material, infrastructure and technology are seamlessly integrated in lifelike systems – not componentized, as in machines	Designers need to appreciate that the outcomes of lifelike systems may be shaped within limits and offer multiple readings of spatial programs, such as the Hylozoic Ground chemistries	The active interface of dynamic droplets is embedded in the environment and interfaces with many actants at different scales, which interact and even transform each other to produce highly unique and individual effects
Environmental sensitivity	Lifelike materials are sensitive to, shaped by and dependent on their environment	Designers need to characterize and even manipulate the environmental, spatial and chemical programs that will help to develop appropriate tactics for working with lifelike systems, such as the mineral and carbon dioxide content of the Hylozoic Ground flasks	In the presence of dissolved carbon dioxide, Hylozoic Ground chemistries may produce crystal growth that reflect the amount of greenhouse gas in the environment over the duration of the installation
Programs	Lifelike systems enable the differential spatial and temporal distribution of matter through their embodiment	Designers may use morphological computing techniques to manipulate lifelike chemistries. This flexible language may be combined to produce different effects, e.g. the spectrum of behaviours observed in the Bütschli system	Adding minerals to the bodies of Bütschli droplets changes their chemical programs so they begin to produce solid structures
Character	Lifelike materials give rise to soft architectures	Designers can make use of spatial spandrels in under-imagined places, buoyant media and embryological programs, and develop them as sites and opportunities for soft architectures, such as synthetic soils in cavity wall spaces	Flexible Traube cell bioscaffolding extensions can be shaped by gravity, which can extend structures from 4 cm to 60 cm

Continued **Table 16.4:** Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Site and context	Soft architectures require procurement systems and infrastructures that enable liquidity	Rather than designing the event itself as an end point, lifelike systems warrant the production of spatial programs that shape context. While lifelike systems do not guarantee a specific event they are agents that increase the fertility of a site and make it more likely that a set of material relationships will bring about a possible spectrum of anticipated events	Transitions being made from dry to wet façades e.g. IBA Hamburg and Arup (Steadman, 2013)
Slowness	Dynamic chemistries exhibit the slowness of the material world as they grow and self-assemble through analogue computing processes, whose calculations occur at the quantum scale	Lifelike systems exhibit relative slowness that designers may deal with by exposing time parallaxes that are usually imperceptible, such as the fast-interacting neural network contrasted with the slow-changing dynamic chemistries in the Hylozoic Ground installation. Comparing these systems within the installation's spatial programs – as a form of experimental relativity – reveals time slippages that may be experienced as uncanny encounters	Banding patterns in the Hylozoic Ground Liesegang ring plates evolve over the course of several days to months
Porosity	Chemical assemblages produce bodies that are entangled with many systems	Designers may provoke transformation within lifelike systems by designing spatial programs that facilitate porosity, as they are susceptible to invasion and/or infusion with other spaces and bodies	Bütschli droplets show a range of behaviours where they spontaneously aggregate and disperse according to local chemical cues and mutual interactions between individual actants

Continued **Table 16.4:** Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Inorganic sympathy	Lively chemistries originate from the non-living realm and ultimately return to it	Design programs, therefore, may incorporate the inevitability that lifelike programs will become inert. Designers may seek to delay this inevitability by, for example, providing infrastructural support and the abundant flow of nutrients through the system	Bütschli droplets exhibit inorganic sympathy and become inert when their osmotic 'skins' occlude the oil/water interface. Once this condition has been reached they cannot be fully reanimated by breaking the skin to reactivate the reaction.
Parallel processing	Molecular interactions enable materials to respond to overlapping spatial programs	Lifelike systems materialize outputs in the presence of overlapping or conflicting spatial programs, without needing to know the outcome in advance	Modified Bütschli droplets simultaneously process a range of inorganic salts and convert them into complex heterogeneous structures
Multiple scales	Lifelike materials simultaneously operate over a range of scales and may produce unique scale-specific effects	Designers may construct spatial programs that potentially work across parallel worlds (Deutsch, 1997)	Modified Bütschli droplets act locally to produce crystalline microstructures and also function as organs within an architectural-scale cybernetic body
Non-linearity	Lifelike materials are unpredictable and may undergo phase changes in behaviour and/or collapse around tipping points	Design paradigms that work with lifelike systems need to be open and robust to deal with the unpredictability of living systems	Turing banding and phase change behaviours occur in the Bütschli system
Technology	Operations are directed through the formation of assemblages	Lifelike systems operate through the technological platform of assemblages. They are able to respond flexibly to changing spatial programs in environmentally sensitive ways and therefore behave variably within definable limits of probability to offer a range of solutions to any particular design challenge	Bütschli droplets are attracted to each other and spontaneously aggregate in population-scale formations

Continued **Table 16.4:** Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Soft control	Assemblages can only be orchestrated, not commanded, as they are probabilistic	Lifelike systems do not come with a push button and respond to soft (facilitative continual nurturing), rather than hard control systems (energy-intensive command). They also possess an independent chemical 'will', which needs to be negotiated and engaged by designers, rather than subdued	Changing the internal and external conditions of the system, such as using chemical attractants to induce cluster formation, may influence Bütschli droplets.
Codesign	Lifelike materials continually engage in material exchanges and forge networks. They therefore continually influence their surroundings and shape them in acts of codesign	Designers need to identify synergies between actants so they may become codesigners. The architect as codesigner extends their individual agency to operate within an assemblage of human and non-human exchanges, which results in the production of architectural design outcomes	Many actants shape the construction of the Vibrant Venice artificial reef, such as marine organisms, humans, tides and smart droplets.
Multi-disciplinary	Lifelike behaviour is not the exclusive specialty of any one discipline but implies convergence and collaboration around the ideas associated with living systems	Designers may work collaboratively to increase knowledge fields using an 'ecology of practices' (Stengers, 2000)	Hylozoic Ground was produced by an international, multi-disciplinary collaboration
Non-hierarchical	Lifelike materials are forged from 'horizontal couplings' and interactions between agents, rather than hierarchies of top-down or bottom-up programs	There is no hierarchical ordering in lifelike systems as many elements inform the spatial programs that shape assemblage interactions	Bütschli droplets interact in populations without fusing with each other

Continued Table 16.4: Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Boundaries	Assemblages do not possess discrete borders but are porous to energy, matter and information	Designing with lifelike systems requires them to be considered as both objects and systems where the bodies of assemblages may be defined at any given moment but are continually shaped and even transformed by their interactions	Bütschli droplets self-organize as dissipative structures that absorb and release large quantities of matter and energy, and yet appear to have a distinct structure.
Classification	No formal classification system exists for lifelike materials	Oceanic ontologies may be used to relate multiple events within a lifelike system to each other to produce complex, probabilistic spatial maps and topologies	Bütschli droplets may undergo many morphological and behavioural transitions, such as the 'werewolf' moment
Body	Lifelike bodies forged by assemblages are soft, wet and mutable	The mutable qualities of the bodies of lifelike systems requires designers to consider multiple spatial programs and tactics to shape and organize their behaviours and interactions as well as creating a context for unexpected transformations and events. Indeed, a precondition for designing for lifelike systems need a world in flux; for instance, the flux of heat and light coming from the Sun. They need also strong coupling between different types of processes	Traube cells possess structure which is 'seaweed-like' and defined by the processes that shape the production of the cell's membrane, but the system does not possess a formal physical shape and transforms continually
Carbon	Lifelike systems are transformers of their environment and may absorb, fix and recycle carbon-containing compounds	Lifelike systems may create the conditions to design carbon-positive architectures that remove carbon emissions from the environment and incorporate them into their construction process	Protopearls fix carbon dioxide in solution into an insoluble, shell-like, mineral structure

Continued **Table 16.4:** Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Born not made	Vibrant matter is a fundamental quality that exists as a function of the primordial laws of the universe and cannot be acquired	Lifelike agents require a particular place where molecules may productively interact with each other within the limits of their existence. When interactions between molecules are possible, they may produce materials that are born from ingredients and produced through recipes that are made operational through acts of 'cooking', rather than building them using mechanical processes	Bütschli droplets spontaneously arise and self-organize from a field of olive oil and alkali
Equilibrium	Lifelike matter exists at far from equilibrium states and resists the decay towards entropic equilibrium (Schrödinger, 1944)	Designing at non-equilibrium enables the progressive discovery of new relevant questions, revealing the diversity of Nature, and pedagogical systems that enable designers to approach this diversity	Bütschli droplets exhibit qualities of dissipative structures at far from equilibrium states
Metabolism	The active exchange of chemistry across an interface enables lifelike matter to evade reaching entropic equilibrium	Designing with metabolism is a challenge set for ecologists by Morton, where outputs of one set of chemical exchanges may be the substrate that begins interactions between another set of agents to generate 'straightforward environmental images' (Morton, 2007, p.150)	Bütschli droplets consume their surroundings (olive oil) to produce a soap-like product and energy. Droplets lose their lifelike qualities when the interface between alkali and oil is occluded by waste product
Simultaneity	Vibrant matter exists both as an object and as a process	Designers may need to develop tactics and spatial programs that overlap, converge and even inhabit parallel worlds to deal with the paradoxes of lifelike systems	Bütschli droplets are composed of paradoxes – they are simultaneously soft (deformable) and hard (crystalline), as well as being wet (flow) and dry (osmotic structures)

Continued Table 16.4: Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Sustenance	Vibrant matter seeks food and energy sources to resist entropic imperatives and delay reaching equilibrium	Lifelike systems are ‘motivated’ by resources and constrained by their context. Their properties change with time and as they mature. Designers may deal with these qualities through infrastructure and procurement system development, which enable vibrant matter to thrive and have the capacity to profoundly shape its interactions	Bütschli droplets vigorously follow chemical attractants or ‘food’
Velocity	Chemistry possesses mass and therefore works more slowly than digital computing	The speed of natural computing processes is constrained by its embodiment and also possesses an innate polarity and, therefore, directionality, which needs to be taken into account in the design process	Liesegang ring plates are limited in their ability to produce banding patterns by the rate of diffusion, the speed of the reactants and gravity
Rhythm	Vibrant matter exhibits periodicity in its chemical interactions, which are shaped by its molecular and macroscale interactions	When working with lifelike systems designers may consider spatial programs and design tactics that deal with periodicity	Static Bütschli droplets that have not yet reached quiescence oscillate in their crystalline residues with lengthening time periods between each contraction, until they reach equilibrium
Ecological compatibility	Through its innate propensity to form material assemblages, vibrant matter seeks to spontaneously integrate with other material systems	Designers may need to encourage ‘social’ interactions between actants to amplify their desired effects, such as using organic solvents to encourage aggregation and assemblage formation in the Bütschli system	Bütschli droplets actively seek each other out and form satellite colonies

Continued Table 16.4: Design characteristics of lifelike systems

Principle	Observation	Design Decision	Example
Completion	Lifelike materials are constantly changing and are never truly 'complete' until they reach entropic equilibrium	Lifelike processes are open systems that are always complete without fully resolving their design programs	Bütschli droplets constantly change and are also transformed in response to changes in their internal composition, context and environment
Infrastructure and procurement	The vigour of lifelike materials depends on their supporting infrastructures and procurement systems	Lifelike systems carry their own infrastructures that enable their survival, such as Bütschli droplet interfaces. These interfaces may be prolonged and shaped by increasing the flow of elemental media through the porous assemblages	Hylozoic Ground chemistries were enabled through the provision of appropriate infrastructure and supply of resources throughout the installation

programs constructed by the interactions of many heterogeneous assemblages within a site. The unique quality of chemistry is that it is embodied, capable of parallel processing and acts simultaneously as a software and hardware. The relationships between matter and information are not only tightly coupled but also sensitive to environmental changes. For example, modified Bütschli droplets could be manipulated within the cybernetic matrix of the Hylozoic Ground installation by periodically activating them by exposing them to environmental changes such as fluctuations in carbon dioxide, as well as physical alternations within the body of the installation: specifically, the production of heat and light. This very specific form of morphological computing appears to be a transferable practice in an architectural design context. Beesley has continued to develop the chemistry of the Hylozoic Ground installation, through a series of works that incorporate vibrant chemistries in a variety of settings. For example, Traube cells have been grown within Bütschli droplet bodies for the 'Epiphyte Grove' installation at the Trondheim Biennale, Norway (Philip Beesley Architect, 2012) (see Fig. 16.16) and at the 'Radiant Soil' installation at Fondation EDF, Paris (Philip Beesley Architect, 2012) (see Figs. 16.17 and 16.18). Additionally, Leduc cells have been used to 'fix' dissolved carbon dioxide from the surroundings for 'Epiphyste Grove' and also in 'Protocell Mesh' at the Building Centre, London (Philip Beesley Architect, 2013b) (see Fig. 16.19). This series of new works not only establishes ways of working with dynamic chemistries using morphological computing principles, but has also founded methods of collaborating through multidisciplinary, international partnerships.

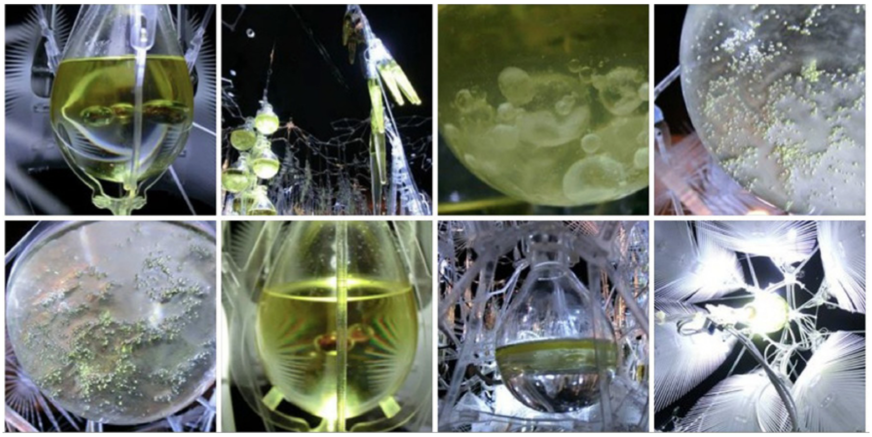

Figure 16.16: The range of dynamic chemistries for the Hylozoic Ground installation is being developed through collaborative work that supports the chemical evolution of the metabolic organs within Beesley's ongoing international exhibitions. Photograph, Rachel Armstrong, September 2010.

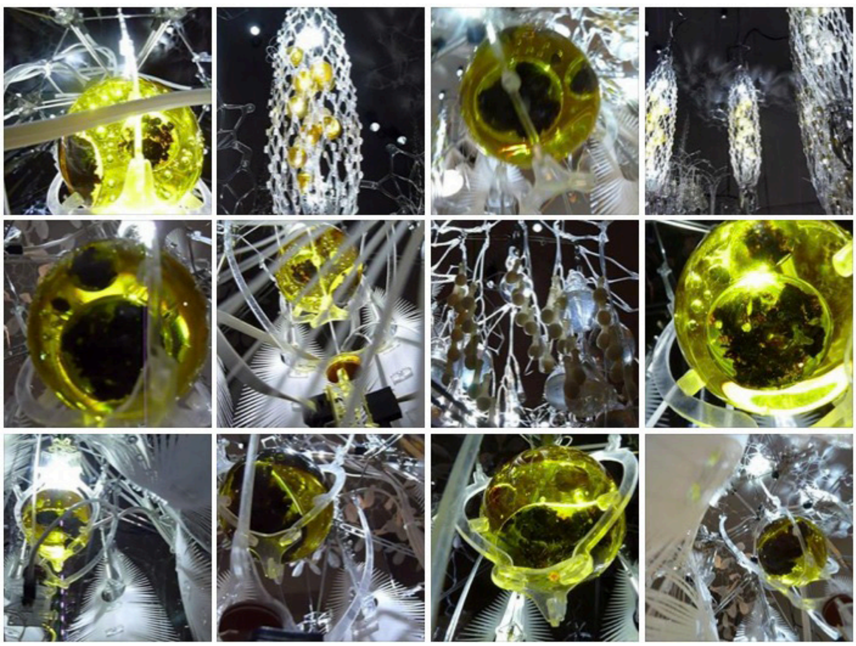

Figure 16.17: Traube cells produce profuse osmotic membranes within modified Bütschli droplets at EDF, Paris. Photographs and collage, Rachel Armstrong, April 2013.

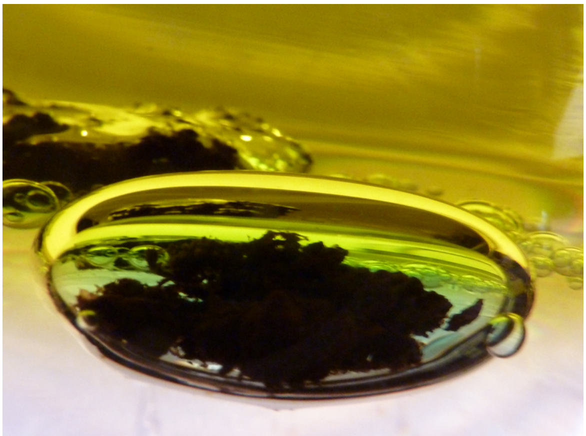

Figure 16.18: Detail of Traube cell incorporated into the cybernetic system at EDF, Paris. Photograph, Rachel Armstrong, April 2013.

Figure 16.19: 'Protocell Mesh' installation at the Building Centre, London. Photographs and collage, Rachel Armstrong, September 2013.

16.11 Procurement and Infrastructure

The liveliness of vibrant matter is dependent on their infrastructures and procurement systems. For example, in the Hylozoic Ground installation, the ingredients for the dynamic chemistries were transported from Marghera on the mainland to the Giardini. Venice's transportation systems are by boat and foot, so the chemistry was sourced from the Explora Biotech laboratory and carried overland to the site. After the show, the chemistries were recycled and reused wherever possible, and where matter was 'spent', then it was emptied into a container and transported back to the mainland for formal chemical disposal. These labour-intense delivery processes mirrored setting up the chemistry flasks and building the dynamic droplet systems by hand. This added a ritualistic feel to the production of the installation, which was reminiscent of the painstaking construction processes employed by Postman Cheval in the construction of the Palais Idéal (Dannies, not dated:a) and the steel Watts towers of Sam Rodia (Watts Towers, 2006–2013) where locally supplied materials, time and human labour are vigorous actants and codesigners of the system.

The Bütschli droplets were modified so they would survive during the three-month installation period and could continue to chemically process and respond to environmental changes, since they were situated in aqueous environments, which were periodically topped up by Explora Biotech. The notion of an architectural-scale liquid infrastructure was further explored in Vibrant Venice, where the city's coastal location provided ubiquitous access to water at the site of action of the 'protopearls' ELT.

Speculatively, chemically programmed droplets would move away from the light when added to the waterways by virtue of a photophobic metabolism to accrete and deposit solid material when they settled under the darkened foundations of the city. Other forms of infrastructural support were also explored in the production of Liesegang ring plates for the Hylozoic Ground installation, using an organic gel matrix. The molecular structure of the gel attenuated chemical interactions, yet also enabled water to move through the system under the influence of gravity. This infrastructural arrangement served to spatialize the dynamic chemistries, inserting time into the system, which is a novelty-producing force (Prigogine, 1997). Further reflection on the role of infrastructure in shaping the effects of vibrant matter in an urban context was considered through the technology of soils. Evolutionarily speaking, soils have provided the fundamental infrastructure that enabled the transition of life from the water to the land.

Accordingly, selecting or designing the right infrastructures when working with vibrant matter may enhance performance in these lively systems so they increase the potency of a site. Further exploration of these ideas could be examined by designing 'artificial soils' to act as complex assemblages of vibrant matter, which do not simply rely on their chemical properties but are also influenced by the spatial and temporal factors that characterize a site. For example, additional layers of complexity could be added to the Liesegang ring plate preparation by creating micro-channels in the system, which is a practice established in microfluidics, and using these channels as an additional transport system within the matrix. This could potentially provide fast (micro-channel) and slow (gel-matrix) transport systems to set up differentials of chemical exchange and interaction, which may give rise to complex, novel events (see Fig. 16.20).

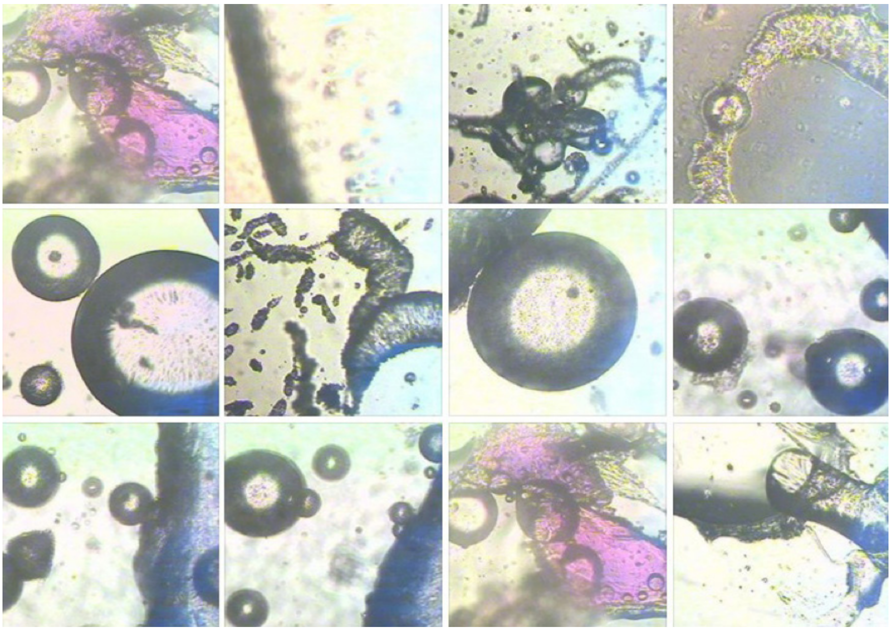

Figure 16.20: Different ELT species potentially offer tools that may provide the materials, infrastructure and technology to enable architects to work with complex chemical fabrics capable of metabolic transformation, such as synthetic soils, which are the building blocks for vibrant architecture. Micrographs and collage, magnification 4×, Rachel Armstrong, August 2012.

16.12 Challenges

My research proposition – that vibrant matter could form the basis for a new production platform with different environmental impacts to that of machines – was a challenging one.

Vibrant matter is a theoretical substrate and has not been applied in a scientific, technological or design context. Yet, the notion of elevating the status of matter so that it could conceptually and physically act as codesigner of systems opened up new spaces for the architectural imagination in the production of spatial programs and design tactics. Potentially, these changes could bring about different ecological impacts to the current damaging impacts that are being wrought by industrial processes.

I worked across the disciplines of architecture and chemistry to raise questions about the spatial and cultural impacts of the proposal, where the two disciplines could be read 'against' the other to map knowledge sets and identify possible knowledge 'gaps'. My multidisciplinary research was supported by working with architects Neil Spiller and Philip Beesley, as well as chemists Martin Hanczyc and Hans Toftlund, who have greatly inspired my practical and theoretical exploration of vibrant matter in architectural and scientific contexts.

My experimental research was conducted in Denmark and Venice, which meant that I did not have full-time access to a laboratory, so I worked in intensely concentrated periods and managed my time very strictly. All experiments, therefore, had to be imagined, designed and resourced within very specific time frames. Consequently, there was little room for troubleshooting and error, particularly when equipment failed, or when techniques did not work to plan. Yet, this also provoked a great deal of creativity and led to the development of, for example, the hygroscopic preparation (see section 8.5.1).

The acquisition of empirical data from my laboratory studies was also challenging, as the capabilities of Bütschli droplets had not been previously studied, and it was not clear what kinds of measurements would be most valuable. Most of the work was, therefore, recorded during microscopy rather than documented by abstracting data from the experiments. Moreover, since my endeavour was to appreciate the richness in the complexity of the material systems I was studying, refining and abstracting these systems seemed counterproductive to the quest to understand the full spectrum of behaviours of these dynamic, dissipative Bütschli systems. Yet, various attempts were made to capture data to clarify the observed processes. For example, spectrometry was attempted, to provide qualitative information about the changes in the chemistry during the dynamic processes, but the spectrum produced was effectively equivalent to water and the analysis did not add much useful information about its chemical transitions. Fluoroscopy proved to be the most powerful tool in observing how the oil/water interface behaved and gave information about spontaneous fusion in the system – yet this could not be counted as 'empirical' research, but descriptive. Much further analysis and development of the Bütschli system is necessary and will be explored in further scientific experiments and design collaborations as the understanding of this system progresses.

Other significant challenges lay in developing a system that had not been previously applied in a technological context. Oil/water droplet systems are not formally recognized as a technology, but have been regarded as models for exploring ideas about the characteristics of 'life'. I addressed this challenge by using action research methods to become immersed in developing the system using laboratory experiments and by making architectural models. Many scientific questions regarding the technological potential of the Bütschli system remain unresolved, and much more in-depth analysis is necessary. This will be addressed through further research and scientific experiments, collaborating with researchers who may bring new ideas and approaches to the formal investigation of this system (Armstrong and Hanczyc, 2013).

A significant technical challenge for working with the Bütschli system was in influencing self-assembly at the microscale in ways that meaningfully address architectural-scale challenges. This issue was addressed by changing the scale of operation and droplet size by slowing down the metabolism of the Bütschli system. Additionally, entangling its chemical interactions with other dynamic systems, such as the Carbon Eaters in the Hylozoic Ground installation (see Fig. 16.21), could also alter the scale at which the effects of dynamic droplets were encountered. The ability of chemical assemblages to horizontally couple their interactions with other (unlike) systems at different scales bestows this emerging platform with a robustness and flexibility that may be transferable to a broader range of different contexts. Working with vibrant matter also required the development of elemental infrastructures to sustain its activity and enable its operations at architectural dimensions. While chemical flasks were sufficient to support the slow interactions of dynamic chemistries in the Hylozoic Ground installation, Venice's lagoon potentially offered a robust, although more inconstant infrastructure for the more vigorous action of protopearls, by being able to deliver a steady stream of nutrients and remove 'waste' metabolites such as surfactants.[83]

Yet, before vibrant matter can be effectively integrated into architectural practice,

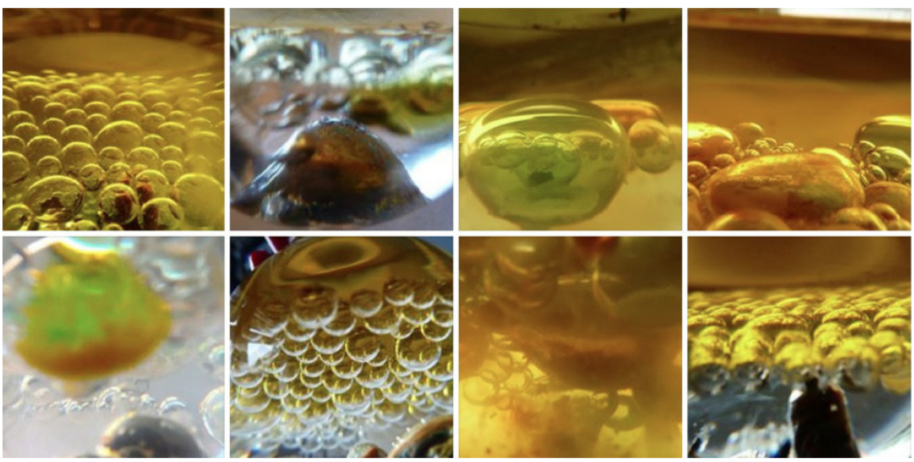

Figure 16.21: Modification of Bütschli droplets enabled the system to be 'technologized' as an assemblage at the human scale. Photographs and collage, Rachel Armstrong, February 2010.

83 Surfactants are soap-like substances, which are produced when oil and alkali are reacted.

new kinds of infrastructures, such as synthetic soils, are needed (Hsu, Mou, and Lee, 1994; Györgyi and Field, 1992; Field, Körös and Noyes, 1974). It is also likely that they will be be integrated with digital technologies, where microfluidics sensors could monitor chemical changes to optimize the performance of vibrant matter. The coupling between a lively body and its various infrastructures may be thought of as an architectural physiology that provides an operational substrate for post-natural fabrics.

Another challenge was that vibrant matter could also reach tipping points that changed its behaviour so that dynamic chemistries were at risk of collapsing or becoming inert when conditions changed. The unpredictability and surprise that is inherent in dynamic chemistries needed to be taken into account when working with vibrant matter, by building contingency into these systems or exploiting it, as in the case of Vibrant Venice, where the dynamic droplet system was expected to change its behaviour should the lagoon dry out.

Working with a system that did not have a discrete control system was also challenging. During my research I learned how to use chemistry as a form of combined hardware and software to manipulate outputs of dynamic chemical systems using morphological computing techniques that operate through soft forms of control. For example, the Hylozoic Ground chemistries were slowed down to make them bigger and more visible within a gallery setting. However, this modification also contributed to their extended lifespan and enabled them to persist for the duration of the exhibition (Armstrong and Beesley, 2011).

Vibrant matter eventually reaches entropic equilibrium and exhibits inorganic sympathy (Bennett, 2011), which has implications for the design of lifelike systems and raises questions about whether they should be maintained, or that their inevitable decay in the system should be regarded as a form of planned senescence. However, this characteristic is not one to be 'solved' by an overriding set of rules but left for individual architects to deal with according to their design programs, aesthetic preferences and philosophical principles (Woods, 2012b).

The lifelike nature of vibrant matter also raises many ethical questions about using living systems to perform work in a technological context. It also provokes moral issues related to how the technology may precipitate new lifelike events as unnatural fertile acts. With the prospect of vibrant matter exhibiting autopoiesis, agency or autonomy, their political status may need consideration as a member of an extended, diverse 'ecological' community (Bennett, 2010, p.viii). Indeed, designing with vibrant matter raises bigger questions about the role of the architect as midwife in the design and implementation of synthetic ecologies and post-natural ecologies. I used speculative fiction as a way of reflecting on possible impacts of ethical and moral issues raised throughout my research. For example, 'The greatest Alluvian poet that ever lived' reflects on the impacts of lifelike technologies in establishing an urban post-natural fabric.

The many challenges that I faced in developing the materials, technologies and approaches towards a practice of vibrant architecture are far from resolved and I have not attempted to deal with them exhaustively. However, my research proposes to offer a taste of the kinds of issues and challenges that architects must face, if they decide to work with systems that are lifelike and, in a way, have a life of their own. ELT may just be able to help us tap into the creative potential of the natural world. Yet this platform does not propose to subordinate Nature and consume it as industrial systems do, but to apply the astonishing power of transformation of the material realm at non-equilibrium states, so that we may innovate more organically within architectural design practice (see Fig. 16.22).

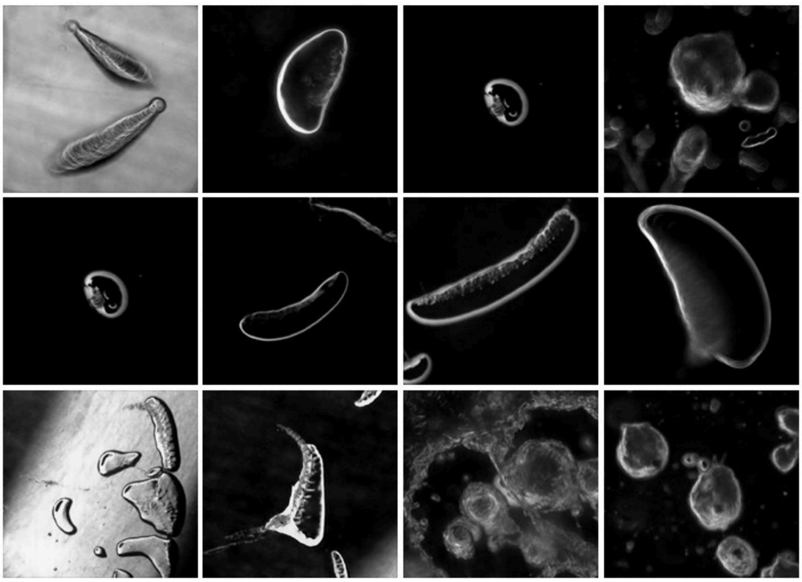

Figure 16.22: Bütschli droplets possess an innate force and creativity that bestow them with the potential to act as codesigners of our living spaces. Micrographs and collage, magnification 4×, Rachel Armstrong, February 2009.

16.13 What Next?

Vibrant matter provides a means of developing new tactics for the construction of dynamic spatial programs that may shape our living spaces. It creates a material context, technical platform and cultural imperative for the possibility of vibrant architecture, which may be realized through further research in the following fields of inquiry, namely:

- Theory (shape of ideas)
- Experiment (developing the context, infrastructures and tools for a novel architectural design practice)
- Practice (cultural adoption and technical implementation)

16.13.1 Theory

Further theoretical engagement with agentized materials that addresses the seemingly irreconcilable split between Nature and machines is needed, which in an architectural context has become politicized around the issues of humanism and environmentalism. My research resists using language that frames my work within either of these polarized positions by avoiding words associated with mechanical systems, such as ‘efficiency’, or evocations that natural systems are intrinsically ‘good’ (Armstrong, 2013f). Yet, seeking equity between humans and non-humans is problematic, especially since anthropocentrism is impossible to avoid completely (Bennett, 2010, p.102) and the humanist/environmentalist dichotomy is framed around a set of already established agendas and ongoing debates (Henderson, 2013). Although vibrant matter and morphological computing propose a new technological platform that is compatible with natural systems and, therefore, speak to a neo-environmentalist agenda,[84] they do not seek to preserve established power systems. Rather, they propose alternative value systems to those that currently exist (Sadler and Smart, 2012). While the dilemma between human and ecological interests is not resolved, the principles of vibrant architecture and morphological computing may be regarded as a step towards establishing new, positive relationships between technology and Nature. These values do not take the form of neo-environmentalism slotted into an old industrial system, but generates different ideals to represent a much broader shared interest in the future of the planet, where the fate of humans and ecosystems are intertwined (see Fig. 16.23).

From a theoretical perspective, perhaps the immediate way forwards lies in developing new value systems that may enable the interests of people and Nature to be equally met. With the advent of a coherent value system, it may be easier to develop appropriate ethical and moral systems to navigate the complex decisions that will shape communities in a post-natural world. New kinds of communities may arise concurrently with a practice of vibrant architecture – from how they imagine and

84 Neo-environmentalists such as Stewart Brand view Nature as a resilient, consumable resource that can withstand a range of assaults and therefore may be harnessed to meet human needs using advanced technologies such as genetically modified crops or nuclear power (Kingsnorth, 2013).

Figure 16.23: Morphological computing aims to develop spatial and temporal tactics that influence the behaviour of materials that are far from equilibrium, so that the body of these systems may help solve computational challenges. This is already intrinsic to the performance of biological systems such as jellyfish, with compliant bodies that help them to move through water without the need for a central nervous system to instruct them. Photographs and collage, Rachel Armstrong, August 2012.

apply the material fabric of our dwellings to the ways in which they may midwife new kinds of Nature into their living spaces. Vibrant architecture represents the start of a very long conversation and series of practical experiments that are essential in changing old paradigms for new – and there is still a long way to go.

16.13.2 Experiment

My research establishes the theory and principles of practice for more ecologically compatible forms of architecture, which directly tap into the non-equilibrium potential of natural forces. A range of ELT was identified that served as a production platform that coupled information, process and matter through spatial programs, which worked through many collective acts of persuasion, cooperation and symbiosis. Yet, there were many limitations in this approach that invoked questions, such as how far ELT could scale, the reproducibility of results and what kind of 'control' systems were possible.

Although my research did not propose to resolve all these questions, or to formally develop the systems as a mature technology, I was able to develop a model system that allowed me to work effectively with vibrant matter in a design context. For example, it was possible to make the Bütschli system produce larger droplets by slowing down their 'metabolism' using an inhibitor (which was a product of the reaction); or additionally, by changing the internal and external conditions of the droplets by adding various mineral solutions, or altering the infrastructures by opening the system to the environment. While the modifications and basic infrastructures explored in my research did not formally constitute the production of a new ready-for-market technology, my experiments enabled me to identify the framework in which these kinds of processes and practices could reasonably exist within an architectural design setting. Further design projects are also necessary to develop a practical understanding of the infrastructural, technological, poetic and aesthetic qualities of vibrant matter. Additionally, further development of the principles of practice for ELT may be established by building a technological portfolio that includes other vibrant matter species such as Traube cells (Traube, 1867) and Leduc cells (Leduc, 1911, pp.124–130). I am collaboratively exploring a range of possibilities by applying these systems in new installation work by Philip Beesley (Philip Beesley Architect, 2012; Philip Beesley Architect, 2013a; Philip Beesley Architect, 2013b).

16.13.3 Practice

My research practice created a context for regarding matter as an active, rather than passive, agent in the design process. Through a series of design-led experiments, a set of repeatable observations were produced that could be applied to a range of contexts. From these findings, it was possible to propose ideas that work towards a theory and practice of vibrant architecture, which extends beyond the existence of visibly lifelike technologies, but also applies to other kinds of active materials and surfaces such as titanium oxide (Woody, 2009). Although the model systems that I developed during my research, such as the Bütschli droplets, are not ready-for-market technologies, they persuasively demonstrate that different kinds of approaches may be possible when thinking about the impact of architecture on the environment. Being aware that all materials possess different degrees of agency that under certain conditions may also be applied technologically extends the possibilities of design practice beyond the current conventions of thinking, such as minimizing energy, reducing resource consumption, or mimicking biological systems. Indeed, the practice of vibrant architecture opens up new exploratory spaces and methods for imagining the relationship between architectural design, materials and the environment.

As such, my research is perhaps most potent when considered as a possible manifesto for change, since it serves as a platform from which to further develop the conceptual and practical approaches for vibrant architecture. While there is a risk that vibrant architecture may be swallowed up into industrial frameworks as soft machines (Spiller, 2007, pp.202–224; Burroughs, 1961), many new developments are beginning to emerge that are facilitating a new way of working, which creates new contexts that may resist this imperative – from Skylar Tibbit's 4D printing (TED.com, 2013b) to Gabriel Villar's printing with abiotic vesicles (Villar, Graham and Bayley, 2013).[85]

Yet, vibrant matter does more than promise new techniques – it provokes and also embodies them. Raising the 'status' of the material world is an essential step in developing more ecologically compatible communities and alternative technological platforms that may underpin human development. This notion of ecology is not merely implied by observing relationships between urban actants differently to predict the movement of resources and people, but is tangible and manifest through spatial, temporal and material relationships. Architectural programs, therefore, form the basis of a synthetic ecology, which is not an inert artefact, but exists as a living network of organizing hubs within the metropolitan system. These material attractors and transformers of matter may take the form of pollution-transforming paints (*Raconteur*, 2012; Fraunhofer, 2012), composting systems (Robbins, 2012) or genetically engineered glow-in-the-dark lighting (Cha, 2011; *Raconteur*, 2012) and change the potency of spaces by precipitating events as orchestrated expressions of architectural design that are subject to soft control systems, like gardening.

During my research, I designed practical tests to explore and examine the validity and limits of some of these ideas using a series of dynamic chemistries. Broadly speaking, these may be regarded as model building blocks of vibrant matter that embody some of the qualities of vibrant matter (slowness, porosity, inorganic sympathy) (Bennett, 2011) and exhibit the strange, unruly, restless materiality that Morton proposes is concealed by contemporary aestheticisms that tame the image of Nature (Morton, 2007). Indeed, matter that is sufficiently lively to exert significant force with human-scale consequences raises architectural design questions – particularly with respect to the relationships between matter, form, program, environment and Nature. Lively materials may respond to many different kinds of architectural design programs that may use overlapping and contradictory cues, or decentralized and deanthropocentrized approaches (Hundertwasser, not dated), where architects are not the sole designers in the system but collaborators that work with the radical creativity of vibrant matter and its collaborating non-human communities.

Yet, if vibrant matter is to be a useful technology, as opposed to a material curiosity, it implies that elemental infrastructures must be more widely distributed within our building fabrics and living spaces. The condensation of elemental flows around these sites will encourage metabolic activity within architectural spandrels, or even to be more publicly celebrated as central features within social spaces, as in 'Hylozoic Veil' in the Leonardo Building, Salt Lake City (Philip Beesley Architect, 2011). Indeed, the development of macrofluidics systems and water computers within

85 Also, my work with the Cronin group at the WETFab workshop in January 2011, combining 3D printing technologies with self-organizing chemistries (WETFab, 2011; Armstrong, 2012g; Adams, 2012).

our buildings and (vertical) gardens, which may be similar to Julius Popp's 'Bit Flow'[86] installation (Popp, 2011), may become vital technologies that help us meet the resource constraints of 21st century urban lifestyles (Pruned Blogspot, 2012) since they can deal with more than one computation simultaneously, such as recycling water stores, processing data and providing contexts in which vibrant matter may reach transformational tipping points (see Fig. 16.24).

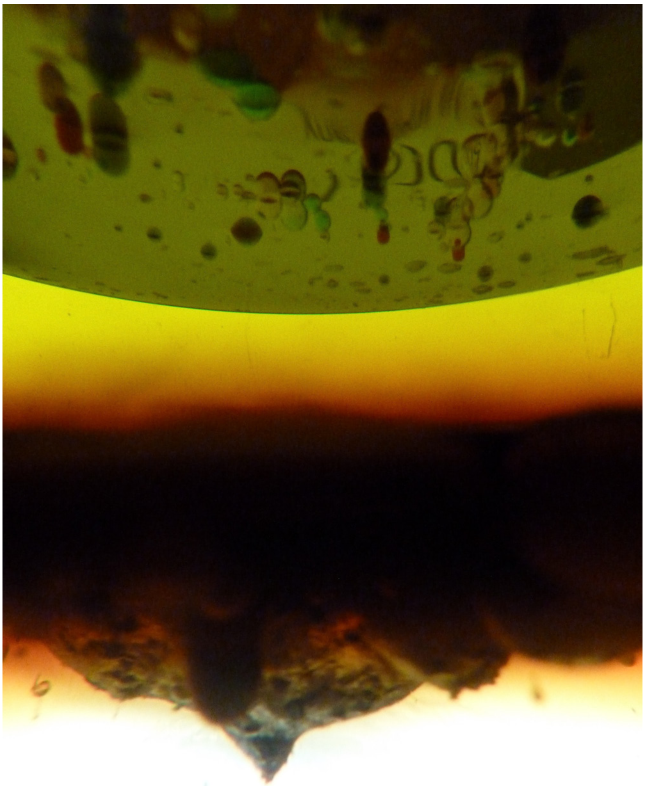

Figure 16.24: The Hylozoic Ground chemistries are transferable technologies that can integrate with the unique chemistry of geographical locations. Photograph, Rachel Armstrong, September 2012.

86 Bit.flow is an anamorphic, liquid computer that consists of coloured oil droplets within a continuous flow of water in sealed, clear tubes. A mechanical pump powers the liquid information and its outputs are letters of the alphabet that can be read by audiences at certain spatial points in the system. Popp drew inspiration from Michel Foucault's provocation on the consequences of Ariadne's thread being torn apart and describes the system as a complex interplay between order in chaos - and chaos in order (Popp, 2011).

16.4 From Here to There: Towards a Practice of Vibrant Architecture

Although we may continue to deny that the material character of the world, or Nature herself, has evolved into a stranger, even more awe-inspiring configuration that is native to this millennium, we have been forced to deal with a new baseline of existence from which we are reimagining the future of our cities. While smart and sustainable cities aspire to produce 'better' forms of industrialization (Armstrong, 2012b), they do not offer Millennial Nature a brand-new relationship – but more of the same kind of approach – even if more considerately applied (Armstrong, 2013e).

Vibrant matter offers the context in which architectural design may develop a new set of approaches, materials and technical systems that reconstruct our relationships with the natural world. Vibrant architecture, therefore, strives towards the production of synthetic ecosystems that blur the historical boundaries between building and landscape, and may even transform our living spaces into rich synthetic ecologies and post-natural landscapes. Indeed, they may establish fertile soil-producing systems, which enrich the environment, generate wealth and even change our value systems so that we are no longer consumers of our environments – but producers of them. Yet, since vibrant architecture can exert forces that can act independently from human agendas, it may offer more than functional value and invokes subjectivity. Vibrant architecture also resists the unimpassioned greyness of the inert industrial landscape that has tamed our notions of ecology (Whitehead, 1970, p.54). For example, vibrant architecture may provide sustenance, income and entertainment for humans, while magnificently co-evolving alongside us. Indeed, vibrant architecture may respond vigorously and effusively to chemical changes in our living spaces (hormonal, mineral, toxins) by reconfiguring them through spectacular acts of continual digestion and secretion that may be as compelling as watching flames leap from a fireplace (Moran, 2008). These creative events may, in turn, be shaped by – but not dependent on – the way we respond to and inhabit them (see Fig. 16.25).

Through our (re)identification with the material world, we may view these post-natural fabrics as being entangled with our own physiology. Such intimate encounters with vibrant architectures may alter our relationship to the environment, where our homes may be regarded as a living membrane that dissolves hostilities between humans and the natural world, so they nourish each other. Yet, like our own bodies, these architectural-scale weavings of natural and synthetic materials are not a panacea, but also create their own paradoxes, difficulties and contradictions, which may raise ethical, cultural and moral challenges. Indeed, this renewed camaraderie with matter will by no means protect us from cataclysmic cosmic events and extinction tipping points, but offer new conduits through which we may negotiate the turbulent material flows of our planet differently. Indeed, the vast substance of our urban landscapes may be regarded as a technological platform and host for a chemical dialogue with the material world. This may be enriched and made diverse through multitudinous acts of architectural design – some of which are initiated by

Figure 16.25: Transformation in materials at far from equilibrium states is enabled through the intersections between elemental fields and flows. Photographs and collage, Rachel Armstrong, August 2012.

humans. Such a detailed and varied fabric may alter the severity of, or even postpone, the damaging consequences of the environmental impacts that we have accelerated over the course of the 20th century. Yet, vibrant architecture does not propose to resolve the probabilistic nature of reality, or collapse it into systems that we can easily command. Instead, it seeks to work with the creativity and strangeness of the natural world, using a new palette of design possibilities that are not to be mimicked, but directly engaged with. By drawing on the eccentric properties of the quantum laws that underpin the fabric of Nature and weaving them coherently into our living spaces, vibrant architecture establishes new ambitions and expectations for 21st century architectural design (see Fig. 16.26).

Vibrant architecture not only produces buildings that enhance biotic environments, but also acts as a point of counter-resistance that provides access to emerging Nature-based technologies, or ELT. To access these possibilities, architects may need to act against the entrenched mores of their profession (Stamp, 2004)[87] before they can reconstruct its philosophy, materiality and environmental impacts.

87 Bernard Tschumi's 1978 postcard reads: 'To really appreciate architecture, you may even need to commit a murder. Architecture is defined by the actions it witnesses as much as by the enclosure of its walls. Murder in the Street differs from Murder in the Cathedral in the same way that love in the street differs from the Street of Love. Radically.'

Figure 16.26: Heterogeneous agents produce post-natural fabrics around the Venetian bioregion. Photograph, Rachel Armstrong, August 2012.

Currently, these points of resistance take the form of an emerging set of lifelike materials and tools, which are already beginning to be incorporated into movements such as Bio Design.

Yet, vibrant architecture has not yet been carved out as a formal practice with distinct aesthetic, programmatic and cultural concerns. It remains open and ready for incorporation within existing systems and ultimately seeks to subvert established power relationships, formal categories of production and the way that architecture is inhabited by inviting non-human codesigners to collaborate in its substance. This may take place through innumerable acts of architectural design, at many scales, whose outcomes are always works in progress (see Fig. 16.27).

Vibrant architecture works to unleash the potency of matter by reaching into its innate, quantum strangeness, and offers access to the unique poetics and sensual palette of the material realm.

It may be expressed through spatial programs and design tactics that give rise to rich and varied architectural experiences. Ultimately, vibrant architecture takes the form of post-natural fabrics that offer a fertile field of new possibilities in vibrant cities where human and non-human communities collaborate and codesign our living spaces and evolve alongside us as expressions of Millennial Nature – to augment the liveliness of our planet rather than diminish it (see Fig. 16.28).

Figure 16.27: The city of Venice may be regarded as a unique site for vibrant architecture, being supported by elemental infrastructures that are capable of transforming its boundaries. Photographs and collage, Rachel Armstrong, August 2012.

Figure 16.28: Juxtaposition of artificial and natural fabrics at Cathédrale Notre-Dame de Paris offers an historical precedent for post-natural, vibrant architecture. Photographs and collage, Rachel Armstrong, August 2012.