Soil Cities: Unleashing Material VLOs with Natural Computing

"Nature is always eluding being conceptualized – not because it transcends the material realm – but because it is relentlessly material" (Morton, 2007, p70).

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At the start of the 21^{st} century we exist within the consensual hallucination of Cartesian reality that underpins the modern age. This viewpoint imagines that information and matter are divided and therefore demands we must to choose to design and engineer in one realm, or the other. While we may move back and forth between these media, as yet, there is no readily available technological platform to unite them. Currently, our greatest opportunities lie within the swift, cybernetic realms of algorithms that free us from the brute materiality of the physical world. Conversely, our greatest challenges are in opposing the restless material networks that shape the natural world. These run counter to the order imposed by the virtually conceived, geometric programs that shape our modern cities. Despite their networks of straight lines and perfect arcs, incessant, subversive material acts invisibly unravel these geometries, as a thread of space-time. This matter-vandalism may be witnessed in the gradual wear and tear of buildings, or as sudden and catastrophic natural disasters such as, hurricane Sandy (Bloomberg, No date) and the Sendai tsunami in Japan (NBC News, 2012). While the information age has stripped many veils from the physical realm to try to apprehend the nature of its innate complexity, the insights gathered do not directly manifest in material outcomes but are open to interpretation when they are (re)transcribed into matter. Although modern computing allows us to more precisely place matter using 3D printing technologies, using increasingly 'big' datasets, these techniques operate in ways that do not encourage matter its to act beyond the geometric confines of their organizing voxels. Even when polymers are encouraged to buckle in 4D printing techniques when they come in contact with water (TED.com, 2013), they are nevertheless required to perform according to geometric paradigms. While these principles work well at equilibrium states, they struggle when systems are lively and far from equilibrium – a characteristic of the living world (Armstrong, 2012c). With such constraints on the way matter is imagined and processed, the production platforms that underpin human development have changed little since the age of modern computing. On the other hand, the rate at which we have been able to consume substances and deplete their biotic value because of the speed of utilisation has vastly increased. So, currently we are striving to paternalistically reduce our negative impact on the vitality of the biosphere, through self-imposed 'austerity' measures, whose rhetoric characterises 'sustainable' practices. By engaging with less of more of the same kind of approaches that we currently use, it is hoped that it will be possible to attenuate resource depletion. However, this objective is likely to become increasingly difficult to attain through conservation measures alone as our populations swell by another third by the middle of this century (Armstrong, 2012b)

Of course, paradigm shifts in architectural practice have been proposed to redress the balance of material exchange between humans and the natural world (Schumacher, 2007; Benyus, 1997; Botazzi, 2012). For example, Curtis B. Wayne proposes that a "*fourth architecture*" (Wayne, 2013) is essential if architecture is to be more than an inhabited sculpture. Instead he proposes that our living spaces should be defined by "*shapes that work*" (Wayne, 2013; Horton, 2013). Yet, despite these assertions, Wayne is simply proposing an set of aesthetic preferences are centred on the author's view of functionality and may be considered as a progressive form of modernism. Of course Wayne is not alone in proposing that aesthetic preferences constitute a paradigm shift in architectural design. The biomimicry movement, parametricism and the many versions of Amilo Ambasz's "green over grey" (Dean, 2011, p230) forms of sustainable architecture, also propose to offer something new to the production of space, while fundamentally conserving a modern, industrial approach to the built environment.

Yet, despite our modern tendencies, which may be accounted for by our dependence on Cartesian technologies, architecture fully understands that the material world is an active participant in space making. It shapes our experience of reality, which is not abstracted in images, but engages our senses - the rain does not need our permission to fall, the earth does not require external momentum to turn, nor do black holes petition us before they implode. Indeed, the material realm may be viewed as a Very Large Organization (VLO) that is engaged by, but not run via, humans. This VLO is a distributed network of a myriad of interacting bodies that are distributed in realms far beyond our "pale blue dot" (Sagan, 2007), whose effects shape our lives and wellbeing.

Bruno Latour describes these loci of action as "*actants*" (Latour, 2005, p54), while Deleuze and Guattari's offer the notion of "*assemblages*" (Deleuze and Guattari, 1986, p22), to articulate the potency of the material world as a collaborative engagement of matter that exerts physical effects. Such material collectives may individually exert very weak forces but when coupled through networks of interactions, their effects begin to become increasingly potent. Jane Bennett (Bennett, 2010) applies these concepts to re-empower the material world as a political entity by drawing on the liveliness of matter. She proposes that since the force of material bodies may shape events that can influence human activities, they may also participate in shaping society. For example, our health and wellbeing are shaped by leaking metabolisms in garbage dumps (Bennett, 2010, p6), through the tempermentality of power lines (Bennett, 2005) and the increasingly recognised effects that microbiomes (our bacterial organs) exert on our bodies (Bennett, 2010, p112).

Yet, Bennett does not look to influence or design with the material world, nor shape their interactions through spatial programs. Instead, she sets the stage for architects to recognise the spatial and technological opportunities that reside in the material world, where material VLOs may be thought of as codesigners of our living spaces.

While matter is inert at relative equilibrium, at far from equilibrium states it is lively and susceptible to invasion or infusion with other bodies. Although the possibilities initially appear to be potentially limitless, they are constrained by the laws of physics and chemistry and may also be harnessed by the techniques of 'natural computing' (Turing, 1936).

The practice of Natural Computing embraces broad, overlapping and multi disciplinary practices such as, digital modelling of biological systems, unconventional computing, synthetic biology, complexity chemistry (Armstrong and Hancyzc, 2013; Tangen and McCaskill, 2004-2008; Simonite, 2009) and some aspects of robotics (Hauser, 2013). The main goal of this field is to develop programmable, lifelike systems using a spectrum of platforms to better understand and reflect the properties of living things such as, adaptation, learning, evolution, growth, development and robustness. Owing to its embodiment and its parallel processing abilities, Natural Computing outputs are very different to those produced by machines.

The operating systems of natural computing are based on the actions of assemblages. Being composed of heterogeneous groupings of lively agents, the participating actants amplify each other's effects through emergence. Through these exchanges networks may be forged with other lively bodies without the need for an external energy source.

The following images capture a range of outputs produced by a dynamic droplet system, based on the chemistry of mixing oil and water, which exhibits striking lifelike properties. These characteristics can be harnessed through simple natural computing techniques by manipulating the external and internal chemical composition of the droplets (Armstrong, 2012a).

This series of micrographs reveal the synthetic actions of lifelike dynamic droplets, which can move around their environment, sense it and undergo population scale interactions without the need for any central programming system such as, DNA. Droplets interface with each other exchanging physical and chemical information, which results in the production of microstructures (Figure 1).

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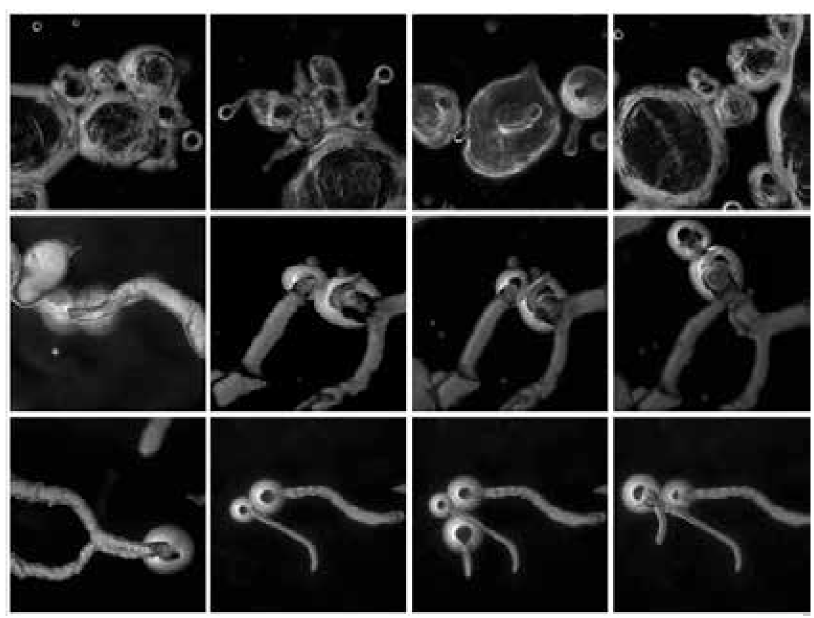
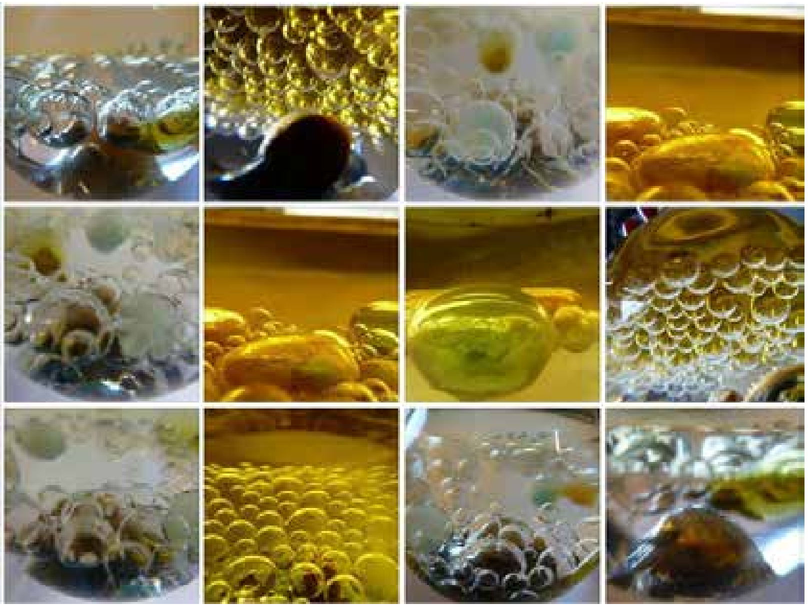


Figure 1: Micrographs by Rachel Armstrong, Magnification x4, 2010.

This series of photographs demonstrates a range of modifications that can be applied to dynamic droplets using morphological computing techniques. In all examples, the droplets have been scaled from the millimeter to the centimeter scale using an inhibitor to increase the size of the droplet bodies. They have also been programmed internally using a simple salt-based chemical program which enables them to respond to dissolved substances in their environment such as, carbon dioxide – which results in the production of striking, insoluble precipitates (Figure 2).



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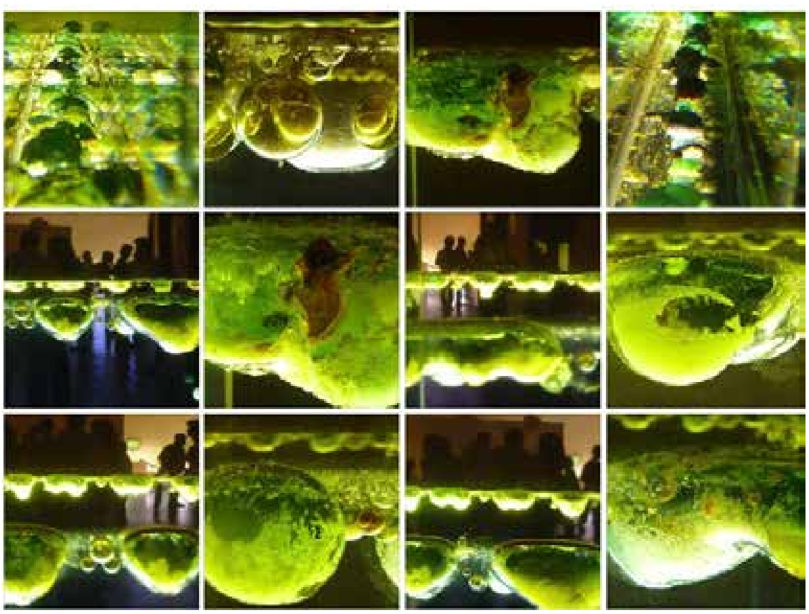
This series of images are from the Synth-Ethic group show at the Natural History Museum in Vienna and show how dynamic droplets may be programmed to demonstrate Turing bands (Turing, 1952). He described these dynamic structures as being responsible for animal patterns such as, 'dappling'. They were physically produced using internal chemical programs based on mineral interactions and also by constraining the dynamic interactions of the system within a 2cms diameter space, which is the mean size of a large droplet (Figure 3).



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However, assemblages do not yet exist as mainstream technology and are not formalized in terms of their engineering, operations or outputs. Yet, these systems are

Figure 2: Photographs by Rachel Armstrong, 2010.

Figure 3: Photograph by Rachel Armstrong, 2011

relevant to architecture since they offer the potential to construct spatial programs and realize them in different ways to machine-based paradigms.

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

	Machine	Assemblage
Component	Object	Agent
Order	Series	Parallel
Power structure	Hierarchical system	Non-hierarchical
Functional system	Machine	Assemblage
Energy	Extrinsic	Intrinsic and extrinsic – spontaneous operations may be prolonged with resource supply
Control	Hard	Soft
Predictability	Deterministic	Probabilistic
Transformation	Binary – on/off	Variable states. Generally conservative but may behave unpredictably and collapse or transform at tipping points

Since assemblages are sensitive to and forge connections with the environment they provide a production platform for a synthetic relationship between technology and our surroundings. For example, Natural Computing may shape the interactions of assemblages so that networks of sustained interactions may be sustained, like growth and repair. They may also be directed towards accomplishing human-centered goals such as, fixing dissolved carbon dioxide into a material form to produce self-assembling mineral structures (Armstrong, 2013d).

Chemical assemblages can operate fully in a range of specific contexts. While machine outcomes are predictable, assemblages operate within a range of operational limits, typical of probabilistic systems, which are defined by internal and external conditions. The complex performance of assemblages creates a design and engineering platform that has the potential to evade the traditional binary divisions between various modalities such as, Nature/machine, humanism/environmentalism and matter/information. Moreover, assemblages facilitate the construction of new ecologies.

Soils are fundamental to the development of all terrestrial ecologies. They are biological cities that are replenished by the diverse communities and countless networks from which they are formed. These giant living bodies contain complex exchanges within the structure of matter, which constitutes a spontaneous form of natural computing. Soil systems are maintained by chemical exchanges that are separated through time and space, which help prolong their decay towards equilibrium (Schrödinger, 1944). The earth was not 'born' with soil but has acquired its living web of relationships over the millennia (Logan, 2007), being attractors of terrestrial life. Plants take root in their complex chemical bodies, where organic and inorganic particles are together into a matrix that harbors fungi and bacteria. These complex assemblages forged by many participating bodies, form a self-perpetuating system that breaks down the bodies of dead creatures and turns them into more soil. The speed of this dynamic conversion through soil assemblages varies. In fertile areas it may take fifty years to produce a few centimeters of soil but in harsh deserts it can take thousands of years. Our living soils age as a consequence of natural causes such as changes in the climate but increasingly their vitality is being impaired as the result of artificial and biological factors, such as over-grazing and deforestation. Ultimately, soils die and when they do— they are gone forever.

Modern cities are literally made of the same kind of stuff as our native soils. What separates a building from soil is simply time's arrow (Prigogine, 1997, p1). Inert materials such as concrete, brick, clay, stone, steel and wood are simply technologically processed agglomerates of molecules that are already present in dirt and will return to dust if they are not maintained. Indeed, classical building substrates could be thought of as soil components that have been reverse-engineered from complex, heterogeneous systems into simple, obedient geometric forms. Nature abhors homogeneity and seeks to re-complexify these substances. So, in the same 5
way that soils have been forged by grinding glaciers over thousands of years, the surfaces of buildings are being weathered and sheared by the same forces that created the primordial dirt. Moreover, they are invaded by microbial life that tears apart their inert infrastructure to reveal, expand and vitalize new surfaces, which can be further colonized by living invaders and through the biological process of succession. Sites of decay can be thought of as unfolding, active chemical interfaces that are symptomatic of the presence of life-giving processes and may be regarded as ecologically potent locales

Although cities (Kazan, 2008) and the earth's ecosystems have been likened to organisms, they technically do not qualify as such. The current definition of 'organism,' or life, does not embrace the pervasive bodies that comprise soils and cities and nor do they possess any centralized genetic program. Yet the similarities between cities and soils are striking as they are complex and share, in principle, many of the characteristics of organisms. Jan Christiaan Smuts noted that materials possessed a unique spectrum of agency, or lifelike characteristics, that ranged from crystals to biology (Smuts, 1998, p88). The importance of lifelike systems lies in their subtle, persistent behaviours, which, without human intervention, spontaneously generate infrastructures and systems where life may thrive. It is this quality that falls apart in cities, as their materiality is eroded with time and not re-enriched through ecological cycles of material exchange. For example, the city of Venice, with no living characteristics, is simply unable to fight back in the struggle for survival against the elements. Yet a myriad of biological agents are extracting minerals from the water and (re)assimilating the city fabric to build their own accretions and microbial 'cities'.

The greatest challenge to our near-future cities is in how we can grasp the full material potential within the material VLOs of our urban environments, to create a new relationship with the natural world. So, rather than depleting resources and polluting our environment with toxic waste we may be purifying and enriching it. So, if we are to embody truly sustainable environments in our cities, then a positive, new relationship between soils and architecture must be established. It is time to end the doom, gloom and skinny corporate corset that has been wrapped around the shapely architectural profession by the industrial sustainability agenda. Indeed, 21st century architectural design must crack a few austerity whalebones with the expanding girth of its voluptuous material VLOs that transform the current paradigm of consumption into a new relationship that is blooming with mutual exchange and generosity between humans and the material world. This is not a call for more primitive lifestyles, but highlights the need for architectural tactics in the development of infrastructures and processes, which promote the use of materials in ways that support regenerative and life-giving systems. It is simply not sufficient to reduce our consumptive practices to uphold imposed conditions of scarcity but essential to develop and promote materially enriching ones, which promote environmental fertility. Specifically, our cities need to re-establish a productive relationship with their soils as spatial assemblage-based technologies that can organize chemical events and transformational sequences (Tschumi, 2012, p60). Soils are complex entanglements of self-replenishing "*vibrant matter*" (Bennett, 2010), which are penetrated by elemental infrastructures. Such vastly complex overlapping programs enable soils to exist as more than simple surfaces but entire bodies, with non-hierarchical architectures, which swallowed Darwin's wormstones through living subtractive and printing process, which were forged by worms (Bennett, 2010, p96). Soils are integrating infrastructures on an architectural scale that enable materials to be transformed through their sequential encounters in the free flow of elemental systems such as air, water, heat and matter through their bodies. Applying the technology of soils within buildings may not only make better use of our waste water and organic matter, and enable us to grow native, not transplanted, greenery (BBC.com, 2013) but also offer flexible architectural tactics that can deal with multiple, overlapping spatial programs.

While complex terrestrial forces spontaneously build natural soils, the possibility of artificially engineering soils within an architectural context creates the opportunity to transform the artificial landscapes that characterize the urban environment, into fertile sites. For example, in Philip Beesley's Hylozoic Ground installation, I developed a series of Liesegang ring plates, which formed banded crystal structures, powered by gravity (Armstrong and Beesley, 2011). These systems explored the change of matter through diffusion/precipitation reactions and established rudimentary principles for developing a simple, soil matrix. This was possible using a homogenous gel that was transformed into self-organizing, evolving layers of different colors and thicknesses, where multiple programs – precipitation, dissolution, colour change, gravity – entangled to create a range of events (structural and process-led) that changed with time.

This Liesegang Ring Plate detail from the Hylozoic Ground installation for the Venice 2010 Architecture Biennale, by Philip Beesley is a dynamic chemical feature that is based on the properties of an active gel matrix contained between specially designed, vertical, perspex plates. Chemical banding, with poetic allusions to soil horizons, has been produced using natural computing by running simple salt solutions through the gel that travel through the matrix under gravitational forces. The reacting species produce salts that are variably soluble and insoluble, which produces the striking banding appearance (Figure 4).

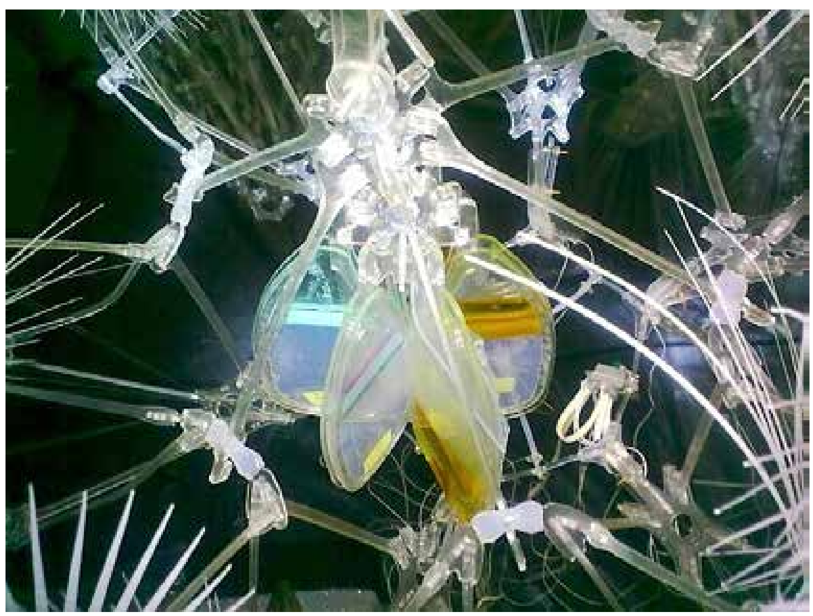

Figure 4: Photograph by Rachel Armstrong, 2010. 4

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Figure 5: Photograph by Rachel Armstrong, 2010.

These Liesegang Ring plates are entangled within the cybernetic matrix of Philip Beesley's Hylozoic Ground installation where they are influenced by natural computing techniques that respond to external physical programs such as, bursts of light, which speed up the chemical interactions in the gel matrix (Figure 5).

Of course, much work still needs to be done before the gel could be functionally likened to the complex self-enriching systems of natural soils. It would, for example, need to facilitate cycles of exchange and feedback, contain air filled cavities, organisms and be capable of compost production. However, these first experiments suggest that it may be possible to design complex, self-regenerating bodies by orchestrating the interactions of multiple biological, physical and chemical agents that goes beyond bio-inspiration and explores new relationships, chemical blends and physical properties.

However, the terraforming ideals that underpin this research area offer opportunities in (re)imagining the nature and functions of soils that go 'beyond' our current knowledge and expectations of soils. For the successful development of artificial soils, it is not sufficient to simply mimic existing biological systems but to develop an additional portfolio of strategies that can provide new ways to increase fertility within desert-like urban landscapes and sustain healthy organic recycling systems. By framing the idea of soils as complex self-generating material assemblages that are designed to support the development of all kinds of habitats, it may be pos-

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sible to develop an architectural design practice that is concerned with many facets of evolving, soil-like systems. These materials may be designed from a portfolio of codesigning agents such as, lifelike chemistries, synthetic and natural biologies. Yet, the degree to which lifelike chemistries will integrate with simple cellular systems such as, algae, is not known. Future research will aim to produce a soil system in the long term that draws from chemical self-organization as a transport system in a soil-like system by using liquids, gels, foams, colloids, coacervates and solid matrices such as, fibreglass, to establish catalytic sites for chemical transformation and physical means of transport. These may then be evaluated to build a coherent system that facilitates meaningful physiological exchanges within architectures, which may for example, act as possible nutrient delivery systems for the propagation of bio-fuel-producing algae, or harvest substances from traditional composting methods.

Such activity could take place invisibly in existing architectural spaces that are under-imagined (Armstrong, 2013a). Currently, cavity-wall insulation is filled with inert materials, such as fiberglass and foams, which perform no useful functions other than to trap insulating air. Yet, within these same spaces soils could act as filters for purifying wastewater, transforming organic matter into heat, provide insulating functions and convert these passive spaces into physiologically active sites. The composting process produces comfortable, slow-release chemical energy that could be controlled by simply letting more or less air into the system. Should our grid systems fail in an emergency then soil-producing units may increase our survival – by filtering grey water, dealing with human waste, growing food, providing heat - as well as increase the city's overall resilience to withstand and recover from potentially catastrophic assaults by enabling its inhabitants to subsist, at least for a while, off-grid. Indeed, composting is already growing in popularity. Armed with "red wrigglers", a species of worm, New Yorkers have started a composting revolution where organic waste is turned into nutritious soil (Robbins, 2012). Yet waste matter may be transformed and applied in different ways too, using different techniques and technologies. For example, composting materials could be pressed into bricks for building, or may even be saleable to soil collectors who would transport fresh compost to farms outside the city. The winners of the Bill and Melinda Gates concept challenge to 'redefine' the toilet have developed novel systems for transforming human waste into electricity with microwaves (Ungerleider, No date), recycling urine to flush (ABC Science, 2012) and turning excrement into charcoal (Rodriguez, 2012). Yet, although the substances involved in soil production are culturally regarded as base matter, design practice is also able to confer new meaning on them. For example, the Philips Microbial Home Probe project (Microbial home, 2011) proposes a series of luxurious products where the house of the future is viewed as a biological ecosystem capable of filtering, processing and recycling what would normally be considered as garbage (McGuirk, 2011). Rather than following the modern obsession for sterility – the idol of a death-centric culture - Philips proposes a new relationship with microbes to run our homes and invite them in as productive members of our community through the process of soil production. For example, bacteria may provide bioluminescent lighting (Myers and Antonelli, 2013, p68-69) and even recycle unwanted plastics (Kanellos, 2009). It is possible that by incorporating the principles and practice of natural computing into our near-future cities, our living spaces will have a much richer infrastructure than today. These soils and elemental infrastructures may nurture living communities of biological and chemical agents whose outputs could be monitored through smart sensors, or even developed as urban gardening practices. They may be conspicuous structures or invisibly woven into the building fabric to make more efficient use of resources. Yet these radical solutions are also compatible with our diverse needs and lifestyles being applicable across a breadth of architec-

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tural styles, property types and geographic locations, so communities may adopt them without sacrificing historical traditions and cultural identities. Different soil producing systems may share the same kind of local variations, complexity and ability to influence biospherical systems as native soils, which transform our biologically desert-like urban environments into fertile, bio-diverse ones (Armstrong, 2013a). Rather than being the horizontal, geometrically defined amount of dirt we have beneath our feet, soil may be regarded as an architectural technology that nurtures the development of vibrant cities. Reconnected to an ecological set of relationships that link the development of cities to soil production, human development may begin to thrive on the multitudinous networks that exist between human and nonhuman communities.

By applying the material and technological principles of natural computing in architectural design practice, it may be possible to develop infrastructures that nurture lively communities of collaborating human and nonhuman bodies to engage with material VLOs rather similarly to the manner in which a personal computer draws from the world wide web. These architectural fabrics may behave similarly to our biotic soils, where, by strategically orchestrating the flow of matter through our cities we may discover new ways of developing our homes and cities as continual, collaborative acts of co-evolution with nonhumans. These developments may extend the traditional reach of architecture beyond the human scale into the realm of material VLOs where networks of assemblage interactions mean that not every action has to be governed by human agency. Natural computing, acting through the language of physics and chemistry provides an approach to engaging city scale metabolisms that act locally and globally through the urban scale production of synthetic soils and post natural landscapes, which are not abstracted from our living spaces, but shape them. Ultimately, the techniques that enable us to deal with the material VLOs in which we are immersed, is no longer a battle between human/nonhuman, virtual/material or local/global but a collaborative partnership where we work alongside matter to forge the fabrics that may ultimately enable us to negotiate our collective survival.

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