A Metabolic Approach to Designing Space

With three images restored from original manuscript to the published version.

Sha Xin Wei

Metabolism's effects:
- Continuity
- Dense Metastability
- Tendency to increase in complexity
- Anti-Entropy (Negentropy)
- Indeterminacy and Non-Prestatability

Metabolic processes
- Photosynthesis (in plants)
- Water near cell membrane

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How can we design material structures as ambients to human and more-than-human living organisms, co-articulating themselves together with their hosted life? By material, I'll mean extensive distributions of matter + energy + affect, which are always in flux.[1] Taking my cue from the recent history of experimental arts in the wake of electronic and digital algorithmic technologies where music is characterized as organized sound, let's for the purposes of this essay regard architectural design as the organization of extensive matter-energy.[2] I add immediately that in the course of this discussion we will also consider the flux of material intensities as functions of relation, recalling a subjective characterization of music as that sound to which intention and attention have been drawn, famously exemplified by John Cage's *4"33'* (1952). In any case, one can see that this approach to architectural design incorporates from the outset a processualist concern with dynamic, flux, change, transformation, which may seem at odds with the classical concept of architecture as the quintessential art of static form. Nonetheless it constitutes a pragmatic and radically empiricist engagement with both concept and practice; design for change in multiple scales and registers is the mandate of our time of anthropogenic climate change. Now, Alfred North Whitehead's compact characterization of a processualist approach – "how an actual entity becomes constitutes what the actual entity is" – suggests that in place of categories of objects defined by their predicates, we focus on the manner, the way objects transform, in short on adverbs.[3]

This volume generally treats how technology mediates between the human (social) and the ambient; in this chapter I highlight the processual aspect of our world, and consider how technologies and techniques mediate between human, biosemiotic, and physical processes. Against this backdrop I propose a core challenge for consideration: how to design our built environments for change, to enable, even affirm life in all its weedy, unruly growth? There are ethico-aesthetic motivations for looking to living processes: on one hand, we can start with the aspiration to create spaces of design that enable, affirm, welcome rather than deaden or exclude life. On the other, we examine techniques and technologies with an eye for how they enable more rather than less sense-making. There too, living process provides insight. In their own respective ways Stuart Kauffman and Giuseppe Longo have argued that living organisms in particular, and more generally metabolic processes 1) are conditioned but not determined by physics, 2) have no pre-statable domains of existence, and 3) obey no entailing laws: there are no a priori structures and rules that determine how living organisms co-structure their ambient. How can we conceive designing space processually, designing space as organized tissues of material processes, with such features of metabolic process? Taking a processualist attitude calls for attending to not merely the products of metabolic processes of design and fabrication, but the manner in which they develop. This manner, bearing the hallmarks of open-endedness and dense metastability, could be productively characterized, in a word, as playful.[4] I look for qualities drawn from living metabolism to enrich our concepts of process and temporality – the sense of dynamic, change, rhythm – that have been desiccated by models from digital algorithmic machines.

This essay proposes an approach to design in a metabolic manner, but to be worthy of its name, metabolic design should be more than the definition of static structures according to a priori form. After all, even a potted plant, if it grows enough, will eventually need re-potting. And invertebrates with carapaces of fixed sizes need to molt as they grow. Indeed, this last example and the examples of coral reefs and lignified cells in trees cue us to the possibility of inactive – no-longer living – distributions of matter as the resultants of metabolic relations between an organism or a colony of organisms and its ambient. The Metabolism architectural movement in 1960s Japan focused in characteristically hylomorphic fashion on formal features such as modularity and an abstract functionalism, but paid no attention to the material processes of wet, living, metabolic earth and tissue.[5] On a systemic scale, the illuminating failure of the Biosphere project in Arizona shows the limits to expanding the purified bubble of a hydroponic plant system to the much larger apparatus of a garden in a self-contained world.

So, metabolic design has to be more than biomimicry, more than biophilic design, and in fact, if we follow through on the implications of non-anthropocentric ethico-aesthetics, more than a matter of pressing living tissues into utilitarian service like filtering synthetic chemicals from the estuaries we have wasted.

In this essay, informed by recent theoretical biology – Stuart Kauffman, Giuseppe Longo, Maël Montevil – but also plant science and general ecology – James Mauseth; Timothy F. H. Allen and Thomas W. Hoekstra – I will consider some essential characteristics of metabolic processes, trying on one hand to adopt a radically empirical approach that constructs characteristics from observing some living systems, but on the other hand avoiding the Pythagorean snare of elevating features of a particular animal or digital computer into a transcendental property. To do this I take inspiration from recent thinkers – Emanuele Coccia, Michael Marder, Francis Halle – who have opened the door for philosophical consideration of vegetal experience, not being but becoming plant, to use Deleuze's tactic.

Features of Biological Metabolism

What are some features of biological metabolism that we might wish to consider as hallmarks also of a metabolic design process? There is no definitive, fundamental list, but for the purposes of this chapter, I draw upon Stuart Kauffman, Giuseppe Longo, Maël Montévil, and Elena Pagni's biological theory of organisms, characterized by irreducible materiality, protentive and retentive temporality and multi-scale / multi-dimensional rhythm, reflexive sense-making, "biological temporal organization [like], … extended criticality, … anti-entropy," and most importantly, open-ended non-prestatability.[6] It's important to underline here that what mathematicians mean by *critical* is quite distinct from political, theoretical, cultural critique. In mathematics, a critical point is a point at which the function's derivative is zero. This means that at so-called critical point *x*, the function is neither increasing nor decreasing. Such a point is also called an equilibrium point, and the value *f(x)* an equilibrium value. Later we will see that the metabolisms of living organisms have a characteristic relation to a particular kind of criticality: metastability.

In their essay "Extended Criticality and Structural Stability: 'Architectures' of Biological Individuation," Giuseppe Longo and Elena Pagni write:

> The radical contingency and materiality of life does not allow to split software from hardware, since only *these* DNA, RNA, membranes … and material organisms as such are actually living. In other words, there is no biological event nor mind process that can be conceived as independent from the physical matter in which it happens.[7]

This strong proposition rules out hylomorphic approaches that posit ideal, a priori forms which pre-exist the event of material formation in the course of material dynamics. Longo and Pagni's proposition implies much more. For instance, one can properly create metabolic processes only by remixing the protoplasmic materials of living tissue. And interpreting this strictly would imply that metabolic design would have to accommodate living things, and incorporate their proliferate activity in a non-hylomorphic way. This notion of material formation calls into play Gilbert Simondon's rich account of individuation, which in his more-than-cybernetic concept of information amalgamates description of material with the shaping and articulating of material, in place of hylomorphic impression of transcendental form upon formless, undifferentiated matter.[8] For the purposes of this account, although not all matter is vital, it is never inert. That is why I prefer to think in terms not of matter but of material, an amalgam of dynamical and boundlessly variegate matter + energy + affect.

What does incorporate mean? It cannot mean 3D printing structures mimicking biological forms, fashioned out of polylactic acid (PLA) plastic, which would amount to a zombie materiality.[9] At the same time, replacing PLA by fungal mycelium and shaping it to the designer's imagination is no less hylomorphic and no more "metabolic" than working with plastic. Indeed, the homogenization of raw material needed in order to eliminate all unplanned formations, whether the knots and whorls in a tree trunk, or the contingently formed fibers of the mycelium from which mushrooms fruit, also eliminates metabolic, structural coupling between the technical individual, the technical object, and their milieu.[10]

Agriculture, forestry, and the design of gardens and parks constitute our most refined technologies (techne) mediating humans and their ambient, and so any practical reconstitution of architectural design should balance the proposals in this essay with those much more mature domains of collective epiphylogenetic memory, to use Bernard Stiegler's characterization of technology. Our larger challenge is to (re)constitute a *metabolic* technology. As Eleni Myrivili, the chief heat officer of the city of Athens Greece, said:

> Carbon is there from the get go, from the materials that we use for the types of construction, from the way we use the buildings, we heat and cool them, the way we eat, the way we consume, the way we move around in our urban environments. So we need to redesign our cities beyond energy efficiency and cutting carbon emissions. We need an urban design revolution, a total paradigm shift that probably needs to be led not by architects anymore, but landscape architects that know more about thermodynamics and soil and the importance of soils for biodiversity and all these things that can really bring about a real paradigm shift, a revolution in design, a new type of urbanity that actually is a different metabolic animal. Our cities of the future will be different metabolic systems.[11]

This essay proposes a thorough-going consideration of what this "different metabolism" could mean, learning from but extending beyond both ancient and carbon-capitalist Anthropocene technologies.

In the next sections, I describe a few characteristic phenomena of living processes, ranging from concrete accounts of material biology to more global phenomena like the temporalities of organisms. In each case, I consider how such characteristics transpose not literally but conceptually to designing space, the organizing of material.

Material Chemistry: Coordinate Growth via Chemotaxis versus Geometry

When growth is modulated by hormones that are produced and modulated by the organism's metabolism as well as ambient chemical and physical processes, the morphological development of the organism inevitably is a function of extensive relations as well as intensive dynamics. One example is the distinct resonances at play between physical processes and hormonally-mediated coordination of metabolic processes that are different in the spiraling of a tendril of a climbing plant in open space, versus a tendril curling around a physical affordance like a twig. Those processes are in turn canalized by an elaborate set of organ structures at multiple scales – from intra-cellular to whole organism and even biome – that are reflexively the morphological and structural result of metabolic development.

Endomembrane Biochemical and Morphological Dynamics

First of all, plant cells differ from animal cells in that they have a proportionately large central vacuole containing water and dissolved salts that play both intracellular metabolic roles and organism-scale structural roles. By changing the permeability of the central vacuole's membrane in response to conditions, the cell can transport more or less water into its vacuole, and thus change the size of the cell by a very large factor. So in hours, a plant and change shape and grow in ways that no animal can. Plant cells also deposit substances that are not to be metabolized and unrecycled elements of disused cellular organelles in their central vacuoles: "a system to excrete wastes never evolved in plants; instead, metabolic waste products are pumped across the vacuole membrane and stored permanently in the central vacuole. The tonoplast is otherwise impermeable to these wastes."[12] Note, this implies an irreversibility which is an instance of how biological processes are typically irreversible, a radical difference with physics, and with abstract algebras that by definition have formal inverses.

All cells, plant and animal, conduct central aspects of their metabolic processes via the action of dictyosomes.[13] These intracellular organelles function in intricate ways to transmute and transport intracellular material: with vesicles forming on one face of the stack of folded membranes, being processed through the stack, and then emerging on the maturing face to release their (transformed) contents. To give an idea of the material dynamics and how different they are in kind from purified mathematical functions or procedural software logic, I quote Mauseth's description:

> A stack of thin vesicles held together in a flat or curved array ... ER [endoplasmic reticulum] vesicles accumulate on one side of the dictyosome and then fuse together and form a wide, thin vesicle called a cisterna... that becomes attached to the dictyosome.... Soon more ER vesicles gather next to this one and form a new cisterna. The first cisterna becomes embedded more deeply in the dictyosome as more vesicles accumulate on that side, which for obvious reasons is the forming face. At the other side, the maturing face, vesicles are being released; their contents have been processed. After separation, vesicles can move to the plasma membrane and release their contents.... The outer edges of dictyosomes form an inter-connected network of curving tubes, and these may absorb the contents from the center of the dictyosome cisterna and then detach and move away. It is not known why some dictyosomes concentrate material in the central cisternae, whereas others use the peripheral ones.[14]

In fact, Mauseth mentions that these identifiable intricate morpho-chemical-energetic processes are part of the much richer and incompletely observed phenomenon of membrane flow, where the membranes of organelles and the endoplasmic reticulum of a cell gradually and in a conditioned manner transmute themselves across organelles.[15] In our anthropic condition, it would be as if the skins of people or surfaces of objects were to flow and transmute into bounding surfaces of other entities with which they have a metabolic relation. Simple transposition of these intricately bio-material phenomena would risk reducing to mere mimicry, or to hylomorphic casting of the ideal onto matter made brute. So let me propose a reterritorializing of the abstract machines corresponding to such processes to a different scale and material context: the re-use of Roman stone in the walls of cities of south England, Gaul and Spain. To carry out that project would require a much more detailed accounting of not only the traces, but also the motivations – utilitarian, but also based on ritual, pride ("romanitas"), or the projection of power – driving the dissolving and reconstituting flows of membranes of built structures from roman monuments to city walls and many other structures in England, from the third to the sixth centuries and later in England, Gaul and Spain, and Italy.[16] And then a "functorial" account would be needed to transpose the relations of relations before we could look for insights from resonances or indeed dissonances generated by the reterritorialization.

152.5

Photomicrograph of dictyosomes. (Fgure 4-22 in James D. Mauseth, Botany: An Introduction to Plant Biology.)

Eating versus Metabolizing

On the macroscopic level of biological organisms, angiosperms – fruit-bearing plants – in their macroscopic relations to other organisms epitomize the relation of mutual aid that stands in sharp contrast with the animal operation of eating: an animal ingesting the material of another living being and disintegrating the metabolic processes maintaining that being. I find it helpful to flip this observation and characterize the vegetal by this distinction: the vegetal is the form of life that converts light into life and enables other life as well as its own.[17] On the most fundamental energetic level, among all terrestrial living beings, plants are the forms of life that metabolize non-biological non-metabolic energy – light from the sun – into biological, metabolic energy. As Eduardo Coccia put it:

> [Plants] transform everything they touch into life, they make out of matter, air, and sunlight what, for the rest of the living, will be a space of habitation, a world. Autotrophy – the ... power ... to transform into nourishment everything they touch is not just a radical form of alimentary autonomy; it is above all the capacity that plants have to transform the solar energy dispersed into the universe into a living body, [to transform] the deformed, disparate matter of the world into a coherent, well-ordered, and unified reality.[18]

This brings us to consider arguably the most fundamental metabolic process of our world.

Photosynthesis

Without walking through all the details of this fundamental metabolic process, look just at the different representations of the photosynthetic process which converts incident light (electromagnetic product of solar physics) into metabolic energy in multiple forms, such as the highly reactive ATP molecule (inside the intricate structure and dynamic chemistry of the mitochondria), and the much less reactive carbohydrates which can be stored in plant cells. Mauseth contrasts the abstract diagram of the photosynthetic process as a chemical equation: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ with a second figure which diagrams the ever-evolving cellular, membrane, fluid and molecular structures, relations and transformations in temporally distinct phases in the soup of material dynamics:

> Light-dependent reactions of photosynthesis occur by means of membrane-bound carriers, but the actual formation of carbohydrate occurs in the chloroplast liquid (stroma). ATP-ADP and NADP + -NADPH diffuse between the two regions. No region of the chloroplast is far from

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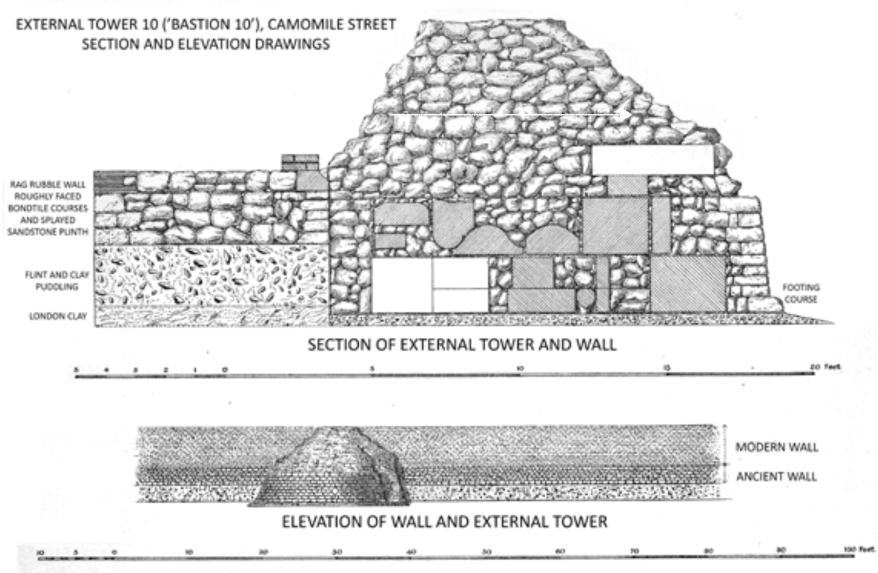


Fig. 6

Elevation and section drawings of tower 10 ('bastion 10') showing the incorporation of earlier materials in the foundations of the tower (from *RCHM*, 1928, p. 101, fig. 25).

Barker, Simon, Penny Coombe, and Simona Perna, "Re-Use of Roman Stone in London City Walls," 335.

> a membrane, so the distances traveled are only a few hundred times the diameter of a molecule.[19]

To represent this either by a bald tally of the difference in energy or even as a chemical equation ignores the material processes in play. As Mauseth writes:

> Although this chemical equation [in the first diagram] succinctly summarizes photosynthesis, it reveals virtually nothing of the reaction mechanism or the many carriers and enzymes that participate. We cannot draw a reaction diagram because photosynthesis does not occur by the direct interaction of six molecules of carbon dioxide with six of water.[20]

Continuity

I register one essential aspect of metabolic process before turning to more global concepts: continuity. Continuity in a precise *topological* sense concretizes the intuition that a continuum has no gaps, holes or interruptions, and a continuous transformation does not introduce or remove gaps, holes or interruptions. The "topological type" is more primordial than dimension and geometry. Thus continuity is a concrete, yet ample and generative concept with which to think the discrete or the so-called digital and its alternatives.[21] What is obvious from observing these intricate metabolic processes is that they are largely continuous, not just as spatiotemporal extension, but as transformations of energies, molecular formations, distributions of fluids, hormones, and ever-evolving morphologies of structured living tissue. Longo and Pagni write:

> Explanations referring to discrete structures may be applied to a few levels of biological organization, but excluding whatever, in a living being, works in a non-discrete way, such as the role of continuous deformation extensively analyzed in morphogenesis since Turing's work….
>
> The physical singularity of the living state of matter cannot be understood without referring to the whole field of complex interactions taking place at each level of an organism's development, among the different and several levels of biological organization.[22]

These complex metabolic interactions are continuous. Why is this important? Digital algorithms, based on discrete, that is, discontinuous, formal structures have calcified contemporary technologies and economies, not only in digital fabrication and measurement, but conceptually in design and technoscientific imaginaries, for example by reinforcing the myth that data = matter = Earth = ground-truth. Indeed, this constitutes the core of what Bernard Stiegler has identified as our contemporary technologies of tertiary retention, such as mass time-based media, social media, and computer technologies, which have "industrialized" individual consciousnesses on a global scale.[23]

In an essay on biological organization and anti-entropy, Bailly and Longo write:

> Many also tried to analyze biological organization in terms of (Shannon's) information: since entropy increase may characterize loss of information, its negation should provide (an increase of) information. Besides its relevance in transmission theory, this approach has inspired new analyses also as for negative entropy in quantum systems.... Yet, both classical and quantum information basically refer to classical or quantum bits, as the discrete mathematical frames are at the core of information and computation theories. In contrast to this, we tried to deal with equations (balance and diffusion, typically) that are better understood in ... *continua* and where Shannon's theory and its quantum variants hardly apply.[24]

With this in hand I turn to more global concepts associated with the metabolic: negentropy, dense metastability, and a precise sense of contingency: non-prestatability of potential states.

Anti-Entropy (Negentropy)

It is useful to define and then set aside the notions of entropy from physics and from (digital) information theory. The usual definition of entropy posits a number-valued function $E(p_1, p_2, ..., p_n)$ of the probabilities *pi* of the possible states of a given system (entity, organism, situation, ...), where the set of possible states is specified in advance. (In the discrete case, *n* is the number of possible states.) This entropy function *E* is required to have certain properties reasonable for a measure of disorder: 1) *E* should be continuous as a function of the probabilities, 2) when the events are equiprobable *E* is monotonic in the number of events – or in Claude Shannon's words, "with equally likely events there is more choice, or uncertainty, when there are more events," and 3) the entropy of a compound event is the sum of the entropy of its subsidiary events weighted by the probabilities of the subsidiary events.[25] Note the essential presumption that the space of possible states of the system is pre-given, and that there is a pre-given probability measure on this space of possible states. The key point is that this is *not* the case for metabolic systems, cells, organisms, or for the epiphylogenetic development of technology.[26] I will return to this fundamental point in the section on indeterminacy and non-prestatability.

p_i

Whereas physicists from Schrödinger onward have proposed to characterize life as that which decreases entropy locally (at the expense of exporting disorder to its ambient), Bailly and Longo carefully define a distinct kind of entropy, what I will call life-entropy, E_{life}, which indexes how much structure has been created in metabolic process. Bailly and Longo set the negative of life-entropy equal to what they call complexity $K = - E_{life}$, a measure of structure (order), and extend thermodynamics by having K satisfy the following inequalities:

$$- K = E_{life} \leq 0 \text{ and } -dK/dt = d(E_{life})/dt \leq 0$$

In other words, complexity – the degree of metabolic structure – is non-decreasing in a living organism. They elaborate their measure of complexity K as the sum of 1) differentiations in cell lineages, 2) the morphological complexity of topological forms and structures, and 3) functional complexity: "relationships established to the fulfilled biological functions; metabolic relations, neuronal relations, interaction networks."[27] Note that these definitions do not reduce readily to scalar quantities. This life-entropy is formally independent of the physicist's entropy, but has the same dimension of energy. The key point is that Bailly and Longo extend thermodynamics to account for how, under the input of energy from outside the system, a living organism creates order (metabolic structure) from order. (Living beings also reverse the local physical entropy, but that is an example of creating order from disorder. An example of organismic order formation opposed by physical entropy would be piling sand into a sand mandala before letting the wind sweep it away.) An example of increasing metabolic structure complexity K would be the morphological-chemical formations of dictyosomes and membrane flow operating in the cell, which we encountered earlier.

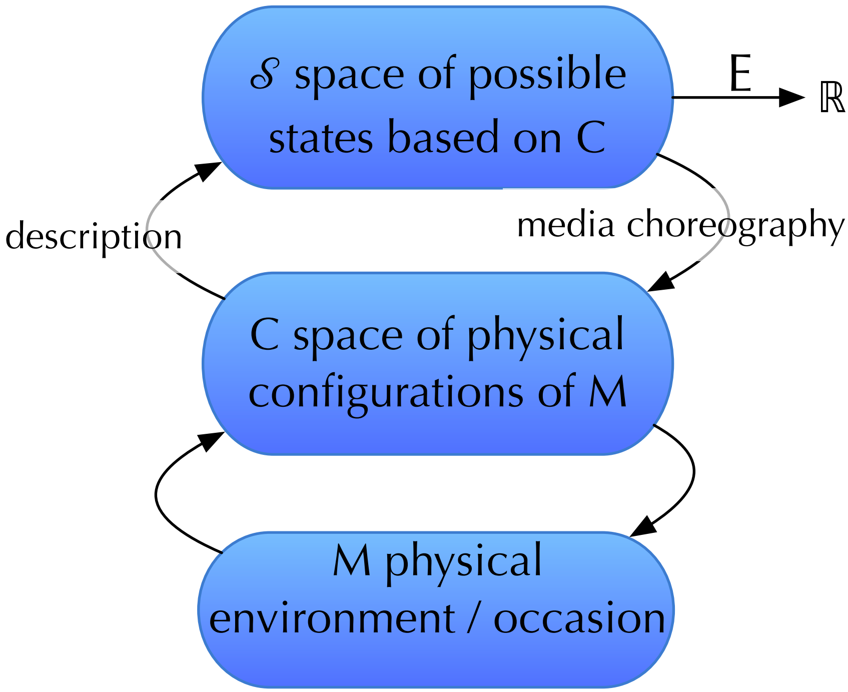
Dense Metastability

In their book *Perspectives on Organisms*, Longo and Maël Montévil discuss a fundamental difference between the dynamics of physical systems and that of biological organisms in terms of the critical points of the dynamics in their state spaces, or more anexactly, domains of possible existence.[28] For the purposes of this paragraph, by a physical "system" I will mean a configuration of time-based media plus matter (including living bodies), plus observables that can be measured with physical sensing technologies like pressure gauges, wind-gauges, thermometers, photocells, microphones, motion tracking devices, together with some durable mechanisms that can modulate the configuration. I put "system" in quotes to single out and remove the common implicit presumption that the entity is finite, bounded, closed, and has a sharp distinction between itself and its ambient. A physical system could be that of a window, a courtyard, a city. The key state space

here is that there is no restriction on the nature and multiplicity of the forces and interpretations that may animate the observed aspect of the dynamics. Therefore what accounts we can make of the dynamic of an organism or a city necessarily omit boundlessly many factors of the dynamic, not least because those accounts depend on the relation between the account's subjects and objects, which in turn arise in the course of the formation of the account.[29] For a start, we focus on (physical) observables in order to introduce the notion of state space, while, to repeat, keeping in mind the boundless openness and indeterminacy of effect. So, to be more precise, when we say a physical system of some environment or occasion, we should always think that we are considering some *particular* configuration of a finite subset of physically observable aspects and relations of the processes in action in that environment or occasion. The first abstraction is to represent the physical system by a choice of finitely many observables that index the configurations of the physical system. Let *M* be the manifold of those possible observables.[30] For example, in a courtyard, *M* could be the compound, non-Euclidean structured space of locations and orientations of the chairs and sun-shades, the parameters controlling the fountain's jets of water, and how reverberant the acoustics are made by the treatment of the space (for example by mechanically controlled drapes or by live acoustic processing via real-time electronics). [31] Configuration c is a set of physical observables and parameters indexing the physical arrangement of material objects + media in a given environment = occasion. State σ is a human-sensible description of a state of affairs associated with a physical configuration.[32] And let S be the space of states, usually not only infinite, but infinitely dimensional. It is at the level of state where the concepts of metastability can be defined.[33] If we construct a notion of energy U on the state space:

$$U: S \rightarrow \mathbb{R}$$

associating a scalar value with every possible state (or more generally a measure to regions in state space), then we can apply the principle of least action to describe how the system may evolve from an initial configuration corresponding to an initial state continuously through various configurations that locally tend to minimize that energy *U*. A critical point is a state σ where the gradient of *U* is 0, meaning small perturbations in any way from $\boldsymbol{\sigma}$ will vary *U* to a vanishing amount. Such a point (and the energy value associated with it) is called an equilibrium. If we look to a second-order – difference of difference – effect on *U* with respect to variations in the configuration, we can distinguish different sorts of critical points: 1) a stable critical point, where the system will tend to settle back to state σ given any small perturbation, 2) an unstable critical point, where the system will tend to fall away from the equilibrium given any small perturbation, and 3) metastable,



Phase space, configuration space, physical system where some perturbations will tend to lead to the system falling away from the equilibrium, whereas under other perturbations the system will tend to return to the equilibrium.

The principle of least action is one of the most fundamental principles of both physics and certain philosophies of change, but that it is not a transcendentally necessary principle for change has become one of the most compelling conundrums of our day.[34] Gilbert Simondon gives a multi-layered account of individuation that does not, I believe, require a least-action principle.[35] But he does adapt the notion of metastability to understand transindividual processes of individuation, and inspired by Simondon's usage, I will propose a notion of generic, or *dense* metastability as another hallmark of life.

Montevil and Longo have proposed, in their theory of organism, that biological organisms are distinguished from physical systems in that their critical points, unlike well-behaved physical systems, are not isolated, that in fact their state spaces have extended regions of criticality, hence their proposal that one of the hallmarks of life is extended criticality (where criticality is to be interpreted in its mathematical rather than political sense). I suggest that the hallmark of a living system co-articulating with its ambient can be more particularly a dense metastability. (As an aside: it bears underlining that thanks to the innumerable metabolic processes ranging from respiration, immune response, sensorimotor enaction, to epigenetic and epiphylogenetic development, the relation between organism and its ambient is topologically far subtler than what naive geometric intuition can afford.) Effectively, an entity or system in stable equilibrium will tend to stay in its given configuration under the impact of any small perturbation; such an entity would be essentially passive, more like a boulder that has rolled to the bottom of a valley than a living entity co-articulating its ambient. If the entity is in an unstable equilibrium, any small perturbation will cause it to "fall" away from the given state. An example would be an egg balanced vertically on its pointed end, equally at the mercy of its ambient as the boulder at rest. If we are considering a configuration space which includes dimensions critical to sustaining the viability of an organism, a falling away could entail the disintegration of the organism's autopoietic metabolism, in other words death. Organisms typically are resilient to certain ranges and degrees of perturbations, so they ordinarily would not be in extensive regions of unstable equilibria, unless they are diseased. Now, one interpretation of a metastable point is a state such that under some perturbations the organism tends to return to the equilibrium, but other perturbations lead to disequilibrium. That living organisms are generically in metastability seems the sine qua non of the indeterminacy and boundlessness of life that is conditioned but not determined by history and physics.[36] Speaking somewhat more precisely, this genericity can be presented by a topologically dense distribution of metastable points, meaning for any state, no matter how small a neighborhood of that state one examines, there is always a metastable point in that neighborhood.[37]

Indeterminacy and Non-Prestatability

Stuart Kauffman, one of the pioneers in studying evolutionary biology from the perspective of complexity and emergence, has argued that unlike informatic or physics models, there can be no pre-given "entailing laws" determining biological development. He characterizes living systems in terms of constraint, work, and catalytic "closures," which operate in a living system that creates "order from order" in structural coupling with, and absorbing energy from its ambient. Kauffman concludes his book *A World Beyond Physics*:

> We can write no laws of motion ... for the emergence of the eukaryotic cell, sex, multi-celled organisms, the Cambrian explosion with its specific marvels of the explosion of diversity of early flora and fauna, promissory of us, fish, amphibians, reptiles, mammals, and primates, let alone the specific proteins that have emerged. We live in an unprestatable, literally unimaginable, myriad of emergent becoming.
> ...
> Thanks to the three closures – constraint, work, and catalytic – life literally constructs itself [toward novel forms]….
> This vast emergent becoming is beyond physics, yet based on it. This is life co-constructing itself and enabling its own vast evolutionary diversification here, and on any biosphere, in the universe.[38]

Longo and Pagni provide a positive characterization of non-prestatability:

> A biolon's [cell, organism, species] domain of existence (which has to be distinguished from the phase space of physics) is not given beforehand, but ... is co-constituted through the interaction of the living entity with the ecosystem to which it also contributes by determining the entity. In this sense, we insist, the passage from one layer [representing the existence of the biolon in a given set of internal and external conditions] to another presents a specifically biological *indeterminacy*, related to the fact that this set of layers can be adopted as such in an *a posteriori* analysis (corresponding to what we call a history of the biolon), but not in a completely *a priori* predictability of its specific developmental trajectory.[39]

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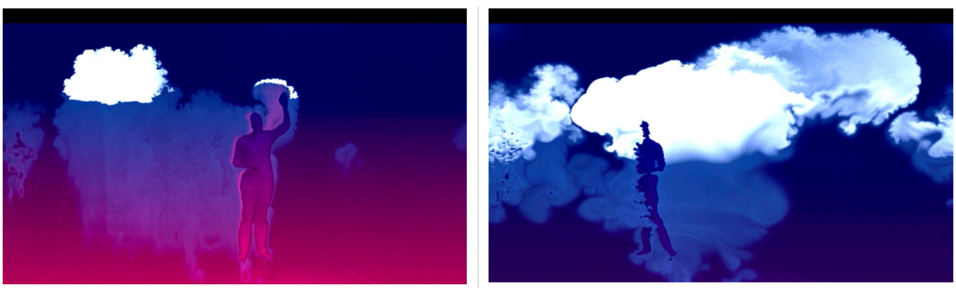

Cloud birthing installation using live weather simulation, Brandon Mechtley, Synthesis.

Synthesizing Implications for Design

We gather the implications for a metabolic design of material processes – elastic, energetic, thermodynamic, wet chemical – at a couple of scales of organization of the built environment, to speculate an approach to design that accommodates indeterminate social, physical and vegetal sense-making. Working, thinking processually and materially, we consider indeterminate novelty and non-prestatable conditions as not only features of life, but of any organized material in flux. In this setting, we consider the delicate question of how to design not forms and categories but the conditioning of events that enable contingent, meaningful, life-affirming co-articulation of built-structures, inhabitants' activities and the ambient environment in the face of indeterminacy. To fully temporalize architectural design, we turn to the composition of not just specific configurations of physical materials, or even of actions and reactions (mechanical, algorithmic interactivity), but of changes in the potential responsivities and affordances of the material (physical + media) environment, in response to both prior design and contingent sense-making, subject-making activity.

A concrete example is the state-based evolution system developed for enlivening richly responsive media environments, and experimentally prototyped in the Topological Media Lab (Concordia University, Montreal, 2001–2012), and Synthesis (2013 to the present). Originally named Oz, and then Ozone, the present incarnation – the SC State Engine – is designed to enable a composer of the behavior of a responsive environment to specify not the moment-to-moment actions of the inhabitants of the space (for example, Louis-Philippe Demers and Bill Vorn's *Inferno*,[40] or of people riding an escalator), nor the moment-to-moment configuration of physical material + media, but the potential responsive behavior of the physical + media environment to any activity whatsoever in that environment.[41]

In the state space S from the description above, a trajectory σ[t] is a particular one-dimensional course of development or evolution of *M*. But this trajectory should be coordinated with and relative to a subject. Different subjects co-articulate different trajectories as they co-articulate an experience in *M*.

Now consider the dynamics, not the physical movements of bodies in physical time and space, but the evolution of states of affairs, in other words movement in S not *M*. The designer can freely define certain regions in state space S, associate them as desired with characterizing configurations – bundles of characteristic observables in the space of observables *C*. Then the designer can define how states in any region of states will tend to flow into other regions of state according to a latent field of tendencies. In the current implementation, the field of tendencies is automatically derived as a gradient on an energetic landscape defined by the composer. For example, the composer can declare that a certain

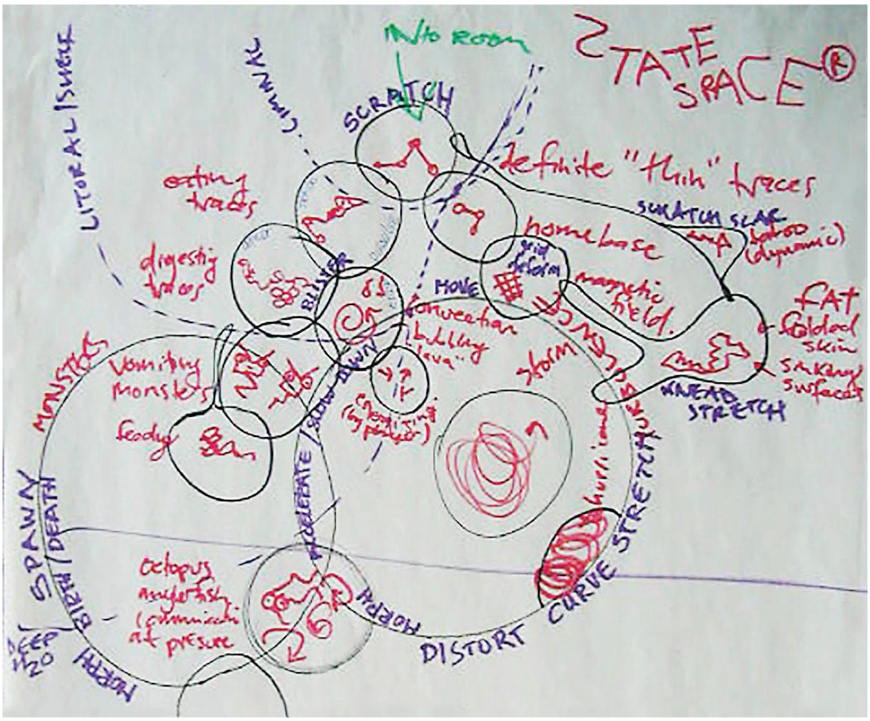

Fig. 1: Composer's metaphorical state space for a playspace event. Source: Synthesis Sponge, FoAM.

configuration, say a crowd of people gathered at the entry to a courtyard constitutes the "prologue" state to the occasion; whereas a single voice by the fountain in the center of the courtyard with a distribution of people around the perimeter of the courtyard constitutes an "aria" state; and a handful of rapidly moving entities with loud music constitutes a "dance" state ; and where people are milling about with loud conversation and medium volume music constitutes an "after-party" state.

The state evolution engine evolves its assessment of state by flowing it according to both observations *C* of the contingent situation of *M*, and according to the field of dynamical propensities defined by the composer's energetic landscape over the state space *S.* Note that the composer does not specify specific sequences of actions or specific sequences of things or media to be placed. Note also that what we have described is not a single unidimensional narrative structure of so-called linear media (video, film, song), nor even a branching narrative ("interactive" game), but a continuum of possible states. Every particular person who enters into *M* will co-articulate with the environment and all the other inhabitants in co-present activity a specific experiential trajectory. This can be as directed, and as concrete as any linear narrative experience.[42]

However one key difference here is that the inhabitant is free to enact changes of state through a continuum of ad hoc or rehearsed activity. No matter what the inhabitant does, the environment will co-articulate ("respond") in concert, much as a swimming pool will ripple no matter how (and no matter how many) people move in its waters. (There is no syntax or schema according to which there is a type of movement to which the water will react, and others that the water will ignore; matter has no syntax checker.) Consider Bailly and Longo's negentropy – life-entropy (and in Stiegler's larger frame of neganthropology): they have defined a life-entropy whose negative is a measure of the never-decreasing richness of structure enabled by life's creation of order from order, which in my terms includes a sense-making in the more precise notions of sense provided by Deleuze and Voss.[43] Perhaps the most enabling aspects of this manner of composing the behavior of a responsive environment is to think of the design of the regional (not finite graph) topology of the state space dynamics as not determining but conditioning the implications of arbitrary activity. Longo and Pagni conclude their essay:

> We do not see DNA as activating developmental processes in general, but as a fundamental chemico-physical structure constraining and canalizing intracellular activity. Mutations and environmental effects could modify these constraining and inhibition capacities in the same respect as activation capacities. This view radically changes the perspective and stresses

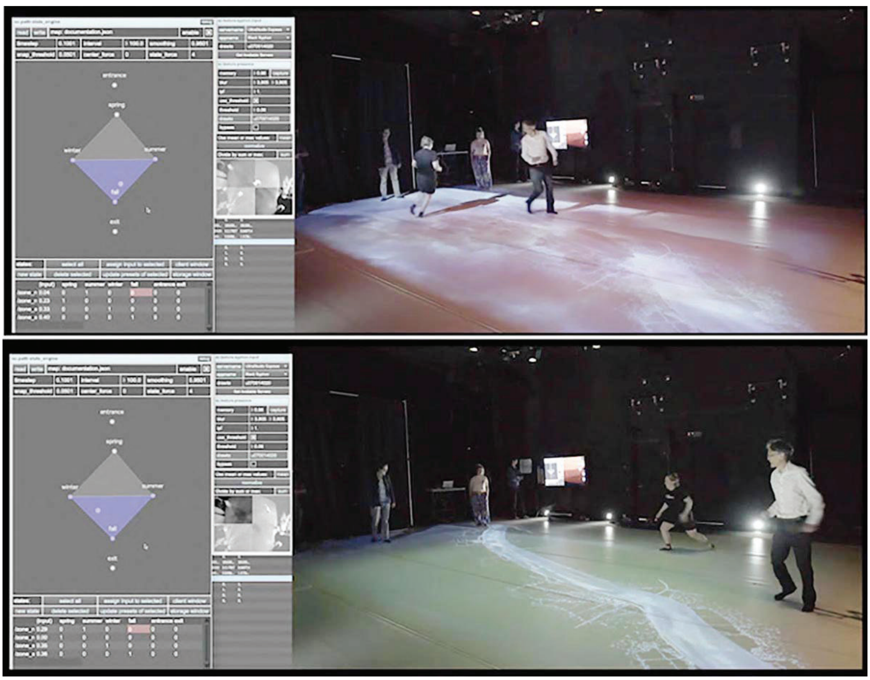

Fig. 2: State-engine playtest, crossing the river leading to state change. Source: "Synthesis State Engine Play Test," Matthews Center iStage, ASU (2019), Synthesis Center; available online at https://vimeo.com/synthesiscenter/stateengine. (used with permission)

> the role of DNA as constraint, in the wider sense that we should consider constraints in biology as fundamental, not just as 'border conditions' like in physics, since they guide or canalize the default state of life, which is activity.[44]

Transposing from phenotypic development to the development of an event, just as the DNA can be understood more properly not as a determining script but a constraint canalizing the organism's co-articulation with its ambient, we can regard the composer's state topology not as a fully deterministic script or ("computer") program for the event, but as a set of conditions canalizing any activities that co-articulate the occasion.

Why is this significant? The continuity and absence of a minimum threshold for an activity to be significant enables the possibility of arbitrarily fine actions that can evoke response, and thus engender sense. This accommodates and enables the dense metastability which is the sine qua non of living and life-affirming material process, and in particular, of a collective, ecosystemic, ethico-aesthetic improvisation of sense.

Notes

1 Sha Xin Wei, *Poiesis and Enchantment in Topological Matter* (Cambridge, MA: MIT Press, 2013), 90.

2 One could add "intentional," but as Maturana and Varela would say, ascription of intentionality (or any telos) depends on the point of view of the one who is making the ascription. "Behavior is not something that the living being does in itself (for in it there are only internal structural changes) but something that we point to." Humberto R. Maturana and Francisco J. Varela, *The Tree of Knowledge: The Biological Roots of Human Understanding* (New York: Random House, 1987), 138, and see generally the discussion in the section "Razors Edge," 129–38.

3 Alfred North Whitehead, *Process and Reality: An Essay in Cosmology*, ed. David Ray Griffin and Donald W. Sherburne, corrected edition (New York: The Free Press, 1978), 64.

4 This notion of play picks up from the final page of my *Poiesis and Enchantment in Topological Matter*:
What our play spaces could offer us are not allegories of other worlds, whether cosmological, political, religious, or psycho-fictive, but events affording playful processes that open life up to more life. Let me close by suggesting a few senses of play that may merit but also escape more careful consideration. There's the play of water lapping against the side of the boat, making the lazy slapping sound that evokes sunlight and fish in the clear water just beyond the reach of your fingers. There's the play, the empty space, between the teeth of interlocking gears, without which the entire assembly of gears would lock up; the teeth guarantee discrete synchrony, but it's the gap that allows movement to be born. And yet that gap is never a vacuum, because the world's structures are always and everywhere part of the substrate magma of the world. There's play in the sense of continuous, infinite-dimensional variation from any given trajectory, that articulates arbitrary degrees of novelty. And there's

play as the endless deferral of definition, a passionate sense making that develops ever more virtuosity in reenchanting the world. Sha, *Poiesis and Enchantment*, 267.

5 See Tian Wang, "A Brief History of Metabolism in Architecture," *Architizer,* April 14, 2022, https://architizer.com/blog/inspiration/stories/history-of-metabolism/.

6 Giuseppe Longo and Elena Pagni, "Extended Criticality and Structural Stability: 'Architectures' of Biological Individuation," *Philosophical Inquiries* 3, no. 2 (2015): 85–114, 88.

7 Ibid., original emphasis.

8 In particular, this makes my approach antithetical to schools of thought predicated on modular and synthetic a priori forms, such as the Metabolism architects in Japan. Christopher Alexander's "no two things alike" is not a formula whose execution would guarantee life-affirming architecture, but is a useful check. Any design-build process that is "canalized" as it individuates automatically yields "no two things alike" simply because of the contingency of the processes of individuation. Indeed, it is not deviation but perfect modular congruency that must be justified and incessantly, even psychotically maintained, against the ever-evolving contingent relations in world.

9 See Sha Xin Wei, "Replacing Thought by Algorithm, Gesture by Mechanism, Organism by Golem," in *European Graduate School Public Lectures*, Saas-Fee, Switzerland, 3 December 2018.

10 Gilbert Simondon, *On the Mode of Existence of Technical Objects*, trans. Cecile Malaspina and John Rogove (Minneapolis: Univocal, 2016).

11 Eleni Myrivili, "A 3-Part Plan to Take on Extreme Heat Waves," *TED Talks*, A New Era, Session 8: Regeneration (13 April 2022, Vancouver).

12 I thank Oana Suteu Khintirian for this observation, and for referring me to James D. Mauseth, *Botany: An Introduction to Plant Biology*, seventh ed. (Burlington: Jones & Bartlett Learning, 2021), 98.

13 Ibid., 105.

14 Ibid., 68.

15 Mauseth writes:
New membrane is synthesized in the ER and then transported by vesicles to growing organelles. Although organelles appear to be distinct entities when viewed by light or electron microscopy, they are actually highly interrelated by this membrane flow. All membranes of the cell, except the inner membranes of mitochondria and plastids, actually constitute just one extensive system, the endomembrane system.
Ibid., 69.

16 Robin Fleming opens an essay on the subject with this capsule summary of the archeological record:
Almost all the stone used in England before the Norman Conquest had been salvaged from abandoned Roman buildings; and this is as noticeable in naturally stone- rich regions (where people could have quarried new stone, if they had had a mind to) as it is in stone-poor ones. Indeed, it was unnecessary to quarry new stone in Britain for at least 600 years after Rome's fall, because so much worked stone was available from derelict Roman sites.
Fleming goes on to detail a type of incorporation that was not simply pragmatic but for ritually charged activity. Robin Fleming, "The Ritual Recycling of Roman Building Material in Late 4th- and Early 5th-Century Britain," *Post-Classical Archaeologies* 6 (2016): 147–70. See also Simon Barker, Penny Coombe, and Simona Perna, "Re-Use of Roman Stone in London City Walls," and related essays in *Roman Ornamental Stones in North-Western Europe: Natural Resources, Manufacturing, Supply, Life & After-Life*, ed. Catherine Coquelet et al. (Namur: Agence Wallonne du Patrimoine, 2018).

17 In their "Manifesto of Urban Cannibalism," (2013) Wietske Maas and Matteo Pasquinelli reject the "political correctness of urban ecology, the petty bourgeois ideology of urban gardens, the self-imposed siege of sustainable development, peak oil

catastrophism and many other current machines of biopolitical control." They cite Reza Negarestani: "any form of religion and politics that expresses and promotes horizontality is in fact the easiest to control and exploit by vertical structures of power. Any polytheism of nature will always be an easy prey of the monotheism of Nature." http://matteopasquinelli.com/accelerate-metrophagy.
However this is an animal-centric view. Plants are far from passive. The most basic anti-entropic form of life is the vegetal: unlike animals, plants do not have to eat – disintegrate their autopoietic modality – other life in order to live. Indeed they proliferate by enabling self and other's proliferation. And they are by far the most powerful anti-entropic processes on earth. And the vegetal is that metabolic which converts non-living energy, sunlight, into living energy.

18 Emanuele Coccia, *The Life of Plants: A Metaphysics of Mixture* (Medford, MA: Polity, 2019).

19 Ibid.

20 Mauseth, *Botany*, 299.

21 One of the twentieth century's great conceptual achievements was to follow the nineteenth-century invention of infinitely many inequivalent metrics (geometries) by a theory of shape, proximity, and transformation that requires no metric at all. Continuity can be defined without any metric, and just by its relation with open sets. See Xin Wei Sha, "Topology and Morphogenesis," *Theory, Culture and Society* 29, no. 4/5, Topologies of Multiplicity, ed. Celia Lury (2012): 220–46; Sha, *Poiesis and Enchantment*, 177.

22 Longo and Pagni, "Extended Criticality and Structural Stability," 90.

23 See, for example: Matt Bluemink, "Stiegler's Memory: Tertiary Retention and Temporal Objects," 3:AM Magazine, 23 January 2020; and Georgios Tsagdis, "Architectures of Thought: Negentropy, Metabolics and the General Ephemeral," *Footprint* 30, The Epiphylogenetic Turn and Architecture: In (Tertiary) Memory of Bernard Stiegler (Spring/Summer 2022): 31–44.

24 Francis Bailly and Giuseppe Longo, "Biological Organization and Anti-Entropy," *Journal of Biological Systems* 17, no. 1 (2009): 63–96, 87, emphasis added.

25 Claude E. Shannon, "A Mathematical Theory of Communication," *The Bell System Technical Journal* 27 (July and October 1948): 388.

26 For a lucid introduction to Bernard Stiegler's concept of epiphylogenesis mediated by our technologies which constitute a collective "impersonalized" exterior memory "of past world interactions that are preserved within the tools function," see Bluemink, "Stiegler's Memory."

27 Bailly and Longo, "Biological Organization and Anti-Entropy."

28 Giuseppe Longo and Maël Montévil, *Perspectives on Organisms: Biological Time, Symmetries and Singularities* (Heidelberg: Springer, 2014).

29 Given space limitations I simply refer to the deep beginning made by Timothy Allen and Thomas Hoekstra to reflexively account for how narratives and policies are constructed, by whom and to what effect within ecological discourse, in chapters 8 and 9 of their book *Toward a Unified Ecology* (New York: Columbia University Press, 2015).

30 For a definition of a manifold, see Sha, *Poiesis and Enchantment,* 185–86.

31 See for example, Meyer Sound's Constellation system: https://meyersound.com/product/constellation.

32 By human-sensible, I mean that it makes sense to a human; and by sense, I mean something that is added to a state of affairs that makes it appear differently, but is neither causal interaction nor an instance of propositional language. For a brief discussion of "sense" in Deleuzian terms, see Sha, "Adjacent Possibles: Indeterminacy and Ontogenesis," in *A Margin of Indetermination: Contingency and Plasticity in Everyday Technologies*, ed. Natasha Lushetich, Iain Campbell and Dominic Smith (Lanham:

Rowman and Littlefield, 2023 forthcoming). For an extended treatment of "sense" from a distinct but nonetheless processualist genealogy, see David Morris's extensive treatment in Merleau-Ponty's *Developmental Ontology* (Evanston: Northwestern University Press, 2018).

33 In this context of dynamics, the concept of criticality has nothing to do with political or analytic critique.

34 See Sha Xin Wei, "Whitehead's Poetical Mathematics," *Configurations* 13, no. 11, Special Issue on Whitehead, ed. Steven Meyer and Elizabeth Wilson (2005): 77–94; and Christopher Alexander's critical considerations of variously inadequate accounts of "emergence of form from the whole," including the principle of least action, in *The Process of Creating Life: The Nature of Order, an Essay on the Art of Building and the Nature of the Universe, Book 2* (Berkeley: Center for Environmental Structure, 2002), 35–48.

35 See Muriel Combes, *Gilbert Simondon and the Philosophy of the Transindividual: Technologies of Lived Abstraction* (Cambridge, MA: MIT Press, 2013).

36 Following Pascal Michon's reading of the pre-Socratics' *rhuthmos*, or Lucretius' swerve, one might argue that all matter has an irreducible indeterminacy. This aligns with Calude and Longo's distinction between randomness, which is always defined relative to a theory and a system of measurement, and noise, which lies outside any theory or empirical regularity. Cristian S. Calude and Giuseppe Longo, "Classical, Quantum and Biological Randomness as Relative Unpredictability," *Natural Computing* 15, no. 2 (2015): 263–278.

37 Strictly speaking, one does not need to say "small."

38 Stuart A. Kauffman, *A World Beyond Physics: The Emergence and Evolution of Life* (New York: Oxford University Press, 2019).

39 Longo and Pagni, "Extended Criticality and Structural Stability," 103, original emphasis.

40 See Louis-Philippe Demers and Bill Vorn's participatory robotic performance: "Inferno," 2015, https://vimeo.com/130670526.

41 See Brandon Mechtley, Julian Stein, Connor Rawls, and Sha Xin Wei, "SC: A Modular Software Suite for Composing Continuously-Evolving Responsive Environments," in *Living Architecture Systems Group White Papers*, ed. Philip Beesley, Sascha Hastings and Sarah Bonnemaison (Cambridge, Ontario: Riverside Architectural Press, 2019), 197–206.

42 See Sha Xin Wei, "Theater without Organs: Co-Articulating Gesture and Substrate in Responsive Environments," in *Living Architecture Systems Group White Papers*, ed. Philip Beesley and Ala Roushan, (Cambridge, Ontario: Riverside Architectural Press, 2016), 276–291.

43 Daniela Voss, "Deleuze's Rethinking of the Notion of Sense," *Deleuze Studies* 7, no. 1 (2013): 1–25, DOI: 10.3366/dls.2013.0092.

44 Longo and Pagni, "Extended Criticality and Structural Stability," 102.

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