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MONSTROUS MATTER: THE MICROBIAL FOUNDATIONS FOR A LIVING PLANET

ABSTRACT:
To confront the escalating climate emergency, a new twenty-first century mythos of matter is essential—one that moves beyond the extractive, industrial paradigms of modernity. This emerging worldview centres on the concept of "monstrous matter:" the unruly, dynamic materiality of life that resists categorization yet operates fully within the laws of physics and chemistry. This matter finds its ultimate expression in Gaia—not as a harmonious globe, but as a dynamic, disruptive, and planetary-scale negotiation between living and non-living forces. Rather than being chaotic or lawless, this matter is profoundly creative, having given rise to the rich biodiversity and material vitality of Earth. Embracing this perspective invites a transition in human development—away from control and exploitation, and toward regenerative practices that align with nature's own cycles of change and renewal. Architecture, as a material and cultural practice, plays a critical role in this transformation. By designing with and for the vitality of monstrous matter—refusing rigid geometries and inert materials—architects can develop environments that support life, adaptability, and ecological flourishing. This mythos offers a hopeful, imaginative framework for rethinking our relationship with the living world.

KEYWORDS
Monstrous Matter, Gaia, Entanglement, Material Agency, Microbes, Unconventional Computing, Metabolism, Holobiont, Oikonomy, Material Change

Monstrous Matter

Rather than conforming to universal abstractions, terrestrial matter operates through what we might call the logic of Gaia: a principle of "monstrous locality." This is not a bland system but a vibrant, geostorical force whose properties erupt from specific, entangled relationships of chemistry, biology, and place. These associations lie within the details of natural systems such as—unique microbial consortia that negotiate transactions within a single rhizosphere; or specific, powerful redox gradients that define the metabolic landscape of a deep-sea vent. Such examples comprise the very sites where Gaia performs her

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material negotiations. From this countless, chaotic multitude of local acts of vitality, a global system of terrifying, emergent complexity emerges—a planet that is a dynamic, unstable, and creative force, rather than a stable sphere of crusted rock. To speak of Gaia is to recognise the monster in Earth's materiality: a self-regulating yet utterly unruly pact between the living and the non-living (Latour 2017: 2).

The truth of this system is not universal but situated and partial, meaning it arises from specific perspectives and contexts rather than claiming objective totality. This situatedness resists the 'god trick', a critique of the illusion of all-seeing scientific objectivity, in favour of the rich, specific complexity of local contexts (Haraway 1988: 581). The challenge, then, is to understand the global through the local without reducing either term.

Monstrous matter's behaviour emerges from myriad local interactions within specific environmental gradients—be they redox potentials (a measure of a molecule's tendency to gain or lose electrons, driving chemical reactions) in the rhizosphere (where plant roots, microbes, and minerals interact), or quantum coherences, coordinated quantum states that may play a role in biological processes such as photosynthesis, in a leaf. These interactions scale into global phenomena forming a hyper-complex biosphere—a product of countless, irreducibly entangled local negotiations.

Despite numerous attempts to define it, terrestrial matter remains fundamentally monstrous, resisting formal rationalisation and categorical boundaries (Armstrong, Hughes, and Ferracina 2020). It privileges the complexity of the local over the simplicity of the global (Latour 1993: 117), challenging classical thermodynamic principles, which traditionally describe energy transformations and the tendency toward disorder, through its refusal to conform to conventional notions of fitness, decorum, or utilitarian purpose.

This wilfulness is most striking in matter's interaction with the fundamental forces of change: (i) entropy-driven processes, which lead toward disorder and randomness, and (ii) material synthesis, the formation of structured complexity that resists entropy. Although these forces are often conceptualised as opposites, when viewed through the lens of monstrous matter, they appear as entangled processes—interwoven and mutually influential, rather than as polarities. This entanglement is irreducibly strange, yet profoundly creative, offering a framework for reimagining human development in alignment with the regenerative capacities of the material world—its ability to self-organise, adapt, and renew.

In the context of the climate emergency, such a multi-perspectival understanding—one that values multiple viewpoints and local contexts—is urgently needed. It must embrace the monstrous character of the living world's matter, not as a problem to be solved, but as a source of creative potential.

This essay unfolds in two parts. The first develops a view of the extended evolutionary synthesis (EES)—a contemporary framework in evolutionary biology that expands on classical Darwinian theory by incorporating developmental biology, epigenetics, ecological interactions, and systems thinking—to

account for the unruly, creative behaviour of matter (Laland et al., 2015). This synthesis challenges reductionist models and embraces the monstrous entanglements of the living world. The second part explores the practical application of this theory: designing ecological technological platforms, which are foundational systems that use the regenerative capacities of living processes to achieve their outcomes. Examples like microbial platforms (using programmed microorganisms as scalable factories) and bio-digital infrastructures (hybrid systems that merge biology with digital technologies) will be considered. Through these, the alignment of human development with planetary processes will be considered by leveraging the adaptive intelligence of monstrous matter itself.

Part 1: Toward a Monstrous Synthesis: Rethinking Matter through Extended Evolutionary Frameworks

Over the course of more than 3.5 billion years, monstrous terrestrial matter has demonstrated a remarkable potential for transformation, giving rise to a vast array of forms and expressions. Far from being a singular or static entity, it possesses its own lifeworld and agency, characterised by a multiplicity of capacities that can generate unexpected outcomes. Among the most effective mediators between entropy-driven change and material synthesis is what we recognize as 'life'. Life does not operate with ruthless efficiency, nor does it offer definitive solutions; rather, its creative potential lies in its persistence and its ability to convert material potential into physical opportunity. Crucially, life as it is lived is not an isolated or closed material system. It exists in a state of continuous flux, functioning through semi-permeable interfaces that are sensitive to the indeterminacies of the quantum realm. These interfaces—where matter encounters differences shaped by both local and planetary conditions—are sites of dynamic exchange. At these junctures, matter may be exuded, transformed, decayed, or absorbed, illustrating the ongoing, adaptive interplay between material systems and their environments.

This perspective, where matter is active and agential, aligns with the principles of the Extended Evolutionary Synthesis (EES)—a contemporary framework in evolutionary biology that expands on the Modern Synthesis (the fusion of Charles Darwin's theory of natural selection with Gregor Mendel's theory of genetics) by integrating developmental processes, ecological interactions, and systems-level dynamics (Jablonka and Lamb, 2005). Moving beyond the neo-Darwinian focus on the "selfish gene," the EES incorporates concepts such as niche construction (organisms modifying their environments), developmental bias (constraints and tendencies in how organisms develop), and—crucially for this argument—the symbiotic origins of complex life.

Lynn Margulis revitalised and evidenced the theory of symbiogenesis in the late twentieth century, proposing that eukaryotic cells emerged through a series of symbiotic mergers between distinct microbial species. This view, now

widely accepted as the serial endosymbiotic theory, reframes evolution as a collaborative, cross-kingdom negotiation (Shan, 2024). Within the EES, life is increasingly understood as emerging from collectives and cooperatives—dynamic assemblages of interacting organisms and environments. One example of this is the holobiont: an integrated collective of host and microbiota whose combined genetics and metabolisms shape development, health, and evolutionary trajectories (Margulis, 1991; Rohwer et al., 2002). This synthesis—integrating physics, chemistry, and biology—offers a theoretical backbone for understanding Earth's material dynamics as a complex, context-sensitive drama in which life is not a passive outcome but a principal actor. By framing evolution as a collaborative process among collectives such as holobionts, the EES enables terrestrial matter to considered as monstrously entangled, creatively generative, and irreducibly local. It is through this lens that we can best appreciate the unruly, emergent character of the living world.

Earth's material restlessness can be conceptually framed through evolving conceptions of Gaia that build on James Lovelock and Lynn Margulis's foundational concept of a symbiotic, planetary-scale system (Lovelock, 1972; Lovelock and Margulis, 1973; Margulis and Lovelock, 1974). Bruno Latour's contemporary reinterpretation emphasizes Gaia's disruptive and political agency, activated through primal, disruptive forces that draw on the fundamental monstrosity of Gaia in Greek mythology. Gaia was the first deity to emerge from Chaos, giving birth to powerful and unruly beings such as the Titans, the Gigantes, the Erinyes, and the Cyclopes. Embracing Gaia's simultaneous "terrifying power" and role as an "astute advisor" who "never commits abominable crimes" due to her cunning nature (Latour 2017: 82), Latour frames Earth's geostory as an active, ongoing negotiation shaped by the entangled agencies of planetary forces and living systems—each operating through strategically manipulative dynamics. Negotiating her existence through dynamic planetary processes—tectonic shifts, meteorite impacts, and glacial cycles—Gaia is experienced as a material potency, one that entangles human and planetary systems to produce tangible, often unpredictable, effects.

Earth's monstrous materiality has never been "brute" or inert, as conceived by Enlightenment thinkers (Newton 2007), nor has it ever been stable. While entropy is the dominant force across much of the universe, Earth represents an exception—where entropy is counterbalanced by a finely tuned constellation of interstellar and planetary conditions. These include our position within the galactic habitable zone (the region within a galaxy that is considered most favorable for the development and long-term survival of complex life), shielded from many cosmic hazards; the presence of a stable G-type main-sequence star (an ordinary, middle-aged star that is converting hydrogen into helium in its core. Our Sun is the closest example) (Nikouravan and Nikouravan 2023); the existence of water at its triple point (the unique combination of temperature and pressure at which water can coexist simultaneously and stably in all three states of matter: solid (ice), liquid (water), and gas (vapour)); a protective magnetic field; a stabilizing moon; tectonic activity (the movement and

interaction of the large, rigid plates that make up Earth's crust and upper mantle, which causes earthquakes, volcanoes, and the creation of mountain ranges); and a life-supporting atmosphere, among other factors. These features collectively create a dynamic environment where matter is not only reactive but also generative. Characterized by fluid, metabolic processes, Gaia's monstrous materiality thrives on the contradictions that emerge as competing forces of change interact and transform to produce complex outcomes. These tensions are not merely abstract or metaphorical—they are materially inscribed in the Earth's geological and cosmological history. The planet's very structure bears the marks of such monstrous entanglements, where planetary processes collide with cosmic forces to generate profound transformations.

Earth has been continuously reshaped by a series of high-energy impact events, including collisions with asteroids (for example, during the Late Heavy Bombardment 4.1 to 3.8 billion years ago, a disproportionately large number of asteroids and comets catastrophically collided with the Earth, profoundly shaping its surface and potentially delivering the water and organic compounds necessary for life) and the oblique impact of Theia—a Mars-sized body believed to have played a foundational role in the formation of the Moon. The remnants of Theia are thought to reside deep within Earth's mantle and core, contributing to the planet's unusually high iron content. This enrichment is not inert; it continues to influence Earth's geodynamic behaviour. The dense, iron-rich core generates a powerful magnetic field that shields the planet from solar radiation and cosmic particles, enabling the long-term stability of the atmosphere and biosphere. Additionally, the thermal and compositional heterogeneity introduced by Theia's impact may act as a driver of mantle convection and tectonic activity, fuelling the dynamic processes that shape Earth's surface and sustain its geological vitality. In this way, the monstrous legacy of Theia persists—not as a singular event, but as an ongoing force in Earth's planetary evolution.

One of the most significant developments in the evolution of Earth's monstrous matter occurred during the Archean epoch, when ancient cyanobacteria-initiated photosynthesis. This biological innovation radically altered both the Earth's crust and atmosphere by introducing oxygen into previously anoxic environments. These localized chemical transformations provided new substrates for further material interactions, setting the stage for large-scale planetary change. The resulting Great Oxidation Events, beginning approximately 2.4 billion years ago, fundamentally reshaped the biosphere. They enabled the formation of new oxidized rock types and created conditions conducive to the emergence of more complex life forms. This transition ultimately supported the development of multicellularity, morphological diversity, and what Hird (2007) refers to as the "higher" expressions of life—organisms that are, in scale and complexity, "big like us" (Hird 2007: 2)

The unique material collectives that define life on Earth today can be traced back to ancient thermodynamic investments—processes that continue to shape our lifeworld by resisting the universal drift toward thermodynamic equilibrium.

These enduring dynamics enable the planet to sustain complexity in defiance of entropy. Despite extensive scientific inquiry, the precise nature of 'life' remains only partially understood, eluding definitive explanation due to its intricate and emergent properties. In this context, Earth exemplifies Gaia as a dynamic, disruptive force that actively negotiates its existence through ceaseless material and geological processes. This interpretation evolves from Lovelock's original conception, laying the groundwork for the Extended Evolutionary Synthesis (EES). Latour spotlights Gaia's monstrosity to reframe Earth as an agential force negotiating its existence through entangled material and geological processes. This framing sets the stage for a reading of matter as monstrous, that describes the unruly, symbiotic, and transformational agencies that defy categorical boundaries and classical rationalisation—such as the intimate link between life and rocks (Wei-Haas, 2016).

Physics and Life

The concept of needing to explain 'life' is a relatively modern development. In ancient thought, life was regarded as a fundamental principle—an animating force that explained other natural phenomena, rather than something requiring explanation itself. This view altered during the Enlightenment, when the material world came to be understood as inert and passive, activated only by external forces such as intellect, soul, or mechanical energy. Matter was consequently redefined as lacking intrinsic agency, responding only to imposed laws and interventions. These assumptions laid the foundation for mechanistic thinking, which continues to shape modern innovation. Within this paradigm, progress is driven by the application of external energy to manipulate matter, rather than by recognising or engaging the inherent vitality and agency of material systems. It was only within this mechanistic worldview that the question of what constitutes 'life' emerged as a distinct scientific problem.

Throughout the twentieth century, machines began to exhibit "disturbingly" lifelike qualities (Haraway 1991: 152), prompting a re-evaluation of the boundaries between the mechanical and the biological. In early classical mechanics, biological systems were modelled as intricate machines governed by deterministic laws. Initially, the highly ordered nature of living systems appeared to contradict the second law of thermodynamics, which states that entropy—or disorder—tends to increase in a closed system. However, living organisms are thermodynamically open systems, embedded within networks of energy and material exchange that allow them to locally reduce entropy and maintain order. The foundational principles for understanding such emergent behaviour—where changes in one component can influence the entire system—were articulated through General Systems Theory, an interdisciplinary framework that studies the common principles, laws, and patterns that apply to all complex systems—whether they are biological, ecological, social, or mechanical—by viewing them as integrated wholes whose properties emerge from the interactions of their parts, rather than from studying the parts in

isolation (Bertalanffy 1968). This framework was further developed by cybernetics, which introduced the concept of self-regulating systems. Within this paradigm, living organisms were understood as information-processing entities capable of achieving homeostasis (the self-regulating process by which a biological organism or system maintains a stable and constant internal environment, despite changes in external conditions) through feedback loops governed by non-linear dynamics. The notion of *autopoiesis* (Maturana and Varela 1972) expanded this understanding by describing life as a self-referential and self-producing network, continuously regenerating its material structure. By the end of the twentieth century, explanations of life increasingly converged on a dynamic interplay between information, physics, and thermodynamics—highlighting the complexity and adaptability of living systems within a materially active universe.

Chemistry of Matter

The open-ended becoming of life, as an evolutionary process, is materially governed and constrained by chemistry (Peters 2012). Traditionally, chemistry has been viewed mechanistically—as a passive backdrop to physical laws. However, recent perspectives emphasise the active role of chemical elements, particularly when considered in relation to specific spatial, temporal, and environmental contexts. Under varying conditions, excitable molecules can make "decisions" about their configuration and distribution relative to other atoms, forming the basis for metabolic change. These molecular interactions unfold across space and time, generating dynamic fields of potential that manifest as patterns. While the modern understanding of chemistry is grounded in atomic weight and chemical properties (Laing 2008), contemporary chemistry encompasses a far more complex landscape. It now includes phenomena such as hydrogen bonding, van der Waals forces, host–guest chemistry, crown ethers, molecular assemblies, supramolecular chemistry, and quantum effects. Indeed, when the chaotic forces of the classical world overwhelm the ability of cells and organisms to maintain their quantum coherence—or their "link" to the quantum realm—this breakdown may offer a compelling way to conceptualise, or even define, death (Macfadden and Al-Khalili 2018: 346). This expanded view of the fundamental units of matter has transformed chemistry into a data-intensive discipline, increasingly reliant on big data, machine learning, and artificial intelligence to bridge theory, experimentation, computation, and simulation (Cova and Pais 2019). This materially grounded, information-rich perspective helps explain some of the most creatively significant transitions in Earth's geostory. For instance, the Cambrian explosion—around 540 million years ago—was preceded by the Great Unconformity, a geological event that eroded ancient rock layers and released oxygen into the atmosphere. This process, occurring roughly 10 million years earlier, facilitated chemical interactions with newer rocks, releasing bone-building minerals such as calcium and phosphate into the oceans. As these minerals entered solution and became

bioavailable, they provided essential building blocks that enabled early life forms to evolve complex biomineralised structures such as bones and teeth (Ou et al. 2015). Such temporally and spatially situated processes foreground chemistry as an active agent in the evolution of life.

Non-classical chemical traits are increasingly being explored as a means of narrating and attributing agency to the earliest processes of biogenesis. While many molecular systems tend toward equilibrium—thereby increasing entropy—certain forms of "lively" matter can sustain far-from-equilibrium states by capturing energy from their surroundings and dissipating it as heat. In doing so, they maintain or even increase internal order and functional complexity (Prigogine and Stengers 1984: 128). At these far-from-equilibrium conditions, persistent material assemblages can gradually reorganize themselves, maximising energy dissipation and acquiring characteristics typically associated with living systems. This phenomenon, known as *dissipative adaptation*, describes the capacity of material systems to evolve by enhancing their ability to dissipate energy while maintaining structural coherence. Under sustained exposure to energy sources—such as light—a random cluster of atoms might, over time, begin to exhibit life-like properties, potentially even developing into a primitive organism such as a plant (Wolchover 2017). This kind of "rebellious" behaviour is essential for understanding how inert matter can transition into dynamic, self-organizing systems. It also offers a compelling framework for explaining how material systems can adapt to and thrive amid change.

A growing body of research has identified long-lasting quantum behaviours that enable material phenomena beyond the scope of classical explanations. For instance, photosynthetic organisms—such as plant cells—capture approximately 98% of incident solar energy, whereas conventional silicon-based solar panels capture only around 28%. This disparity is attributed to quantum coherence, which allows energized electrons to transfer smoothly across molecular structures, avoiding the inefficient "hopping" between states typical of classical systems. This quantum efficiency facilitates a more seamless energy transfer mechanism. While traditional biological models focus on structural components like nucleotides and metabolic pathways, the dynamic nature of living systems can also be understood through the flow of electrons between active bodies. Since Luigi Galvani's seminal frog leg experiments, electrons have been associated with the vital force of organisms, capable of animating tissues and driving physiological processes. Electron flow thus offers a unifying principle that integrates biological function with physical transformation. This is not merely a matter of transferring electricity; when substances gain or lose electrons, their molecular charge and redox potential are altered, resulting in atomic-level changes. Negatively charged electrons are held in orbit by the attraction of positively charged protons. Electrons in outer orbitals are weakly bound and can be liberated by external forces. When atoms lose electrons, they become positively charged cations (positively charged atoms or molecules); when they gain electrons, they become negatively charged anions (negatively charged atoms or molecules). Free electrons moving between

atoms generate electric currents, facilitating energy transmission and transformation across systems.

One of the most compelling characteristics of electron flow is its capacity to extend beyond the boundaries of individual organisms, enabling interactions with non-living entities such as rocks and metals. This uneven distribution of electrons underpins a lively material world shaped by redox and electrochemical gradients. A redox gradient refers to the flow of electrons between molecules based on their relative electron affinities, which helps build electrochemical gradients—zones of potential energy created by the uneven distribution of ions (especially charge and concentration) across membranes. These gradients, often powered by redox reactions, drive the movement of protons against their concentration gradient, generating the proton motive force that fuels life—namely, ATP synthesis (the production of cellular energy) during cellular respiration and photosynthesis in mitochondria and chloroplasts, respectively. In respiration, excess electrons derived from sugars are released through a series of biochemical reactions and ultimately transferred to oxygen—the final electron acceptor in the electron transport chain. Without oxygen, this electron flow ceases, halting the entire process. Yet electrons are not merely classical entities understood electrochemically within molecules or electrically as sources of power; they are also quantum particles, each subject to the probabilistic and non-local laws of quantum mechanics. This complex character allows them to participate in both measurable biochemical reactions and ephemeral quantum phenomena. Far from being immaterial, electron flow is both fleeting and empirically observable—comparable to a moving image on a digital screen or, metaphorically, a material explanation for the soul (Armstrong 2023). Despite its transience, electron flow can be quantified through parameters such as bioelectricity, redox potential, and molecular configuration, offering a tangible and often non-classical link, between energy, matter, and life.

By integrating the diverse behaviours of chemical systems into a twenty-first century mythos of matter, new alliances can be envisioned within a realm rich in reactive agents and dynamic interfaces (Armstrong 2025; Stepney 2025). This expanded material framework enables the emergence of novel bodies capable of inhabiting previously inaccessible ecological and energetic niches. Monstrously enlivened matter thus functions as both a driver and a trickster in the face of change—transcending conventional boundaries and participating actively in its surroundings. Rather than remaining passive, this matter engages in a continuous negotiation with its environment, initiating creative processes that resemble decision-making. Through its capacity for chemical invention, it generates new forms—new "monsters"—that embody the unpredictable and generative potential of material transformation. In this way, matter becomes an agent of its own becoming, shaping evolutionary trajectories through its dynamic and responsive nature.

Natural Computing

Although the potential configurations of enlivened matter are vast, they can be meaningfully explored and better understood through their material expression in experimental settings. These explorations do not aim to reveal universal truths but instead generate local, context-specific responses to ongoing challenges. Such hyper-locality is essential for engaging with change, as the material expression of a tree, for example, differs significantly between equatorial and northern climates. Observed variations are produced by the fundamental plasticity of chemical systems and their capacity to read and respond to specific physical conditions. In excited states, molecules enter a temporary configuration of 'intra-action'—a term used to describe the entangled agency of matter and context (Barad 2007: 33)—before resolving into a formal chemical 'decision'. Within these dynamic fields, particles, atoms, and molecules oscillate, collide, interdigitate, or persist, shaping proximate events in ways that are contingent on the specific circumstances of their interactions. During these fleeting moments, matter can 'choose' its next move through massively parallel computation, guided by both chemical behaviour and environmental context. Alan Turing explored how such decisions manifest as patterns in biological systems. He proposed that symmetry-breaking in otherwise homogeneous systems could produce complex patterns through reaction–diffusion processes (Turing 1952). Inspired by oscillators in electrical circuits, Turing demonstrated that even minor irregularities could trigger nonlinear chemical reactions that generate diverse spatial forms. While modern computing relies on electrons and algorithms, chemistry operates with atoms as both processors and outputs—executing decisions within molecular landscapes that reveal actualisable possibilities, though not always with repeatable outcomes.

The field of natural computing, drawing on Turing's vision of nature as a computational system, seeks to understand the material world through the paradigm of information processing. It employs models inspired by natural phenomena to explore how matter itself can perform computation. In this context, to say that matter can compute is to recognize that physical systems—through their intrinsic properties—can process information, respond to inputs, and generate outputs, functioning as computational entities beyond the confines of traditional digital machines. This is made possible through material processes such as molecular and quantum computing, which rely on iterative and dynamic phenomena, including quantum parallelism (a quantum state where particles are correlated, allowing them to perform multiple calculations simultaneously). These oscillatory patterns—whether orbital paths, pulses, blinks, footsteps, bowel contractions, tides, rainfall, or photosynthetic cycles—operate analogously to the repetitive operations at the core of computation. Yet, unlike digital systems, these material iterations are not uniform, self-similar, or universally replicable (Armstrong 2019: 355). Their inherent variability introduces bifurcations—points of divergence—that compel molecules and systems to make context-sensitive decisions, often leading to irreversible outcomes. These

decisions are not directed by external intelligence but are resolved through the embedded computational capacities of matter itself.

Chemical computation, however, is not boundless; it is genetically constrained through biological mechanisms, particularly the operations of the aperiodic crystal structure of DNA (Schrödinger 1944). These constraints are further shaped by regulatory pathways, where deviations in material expression are interpreted as adaptations or mutations. Advances in systems and synthetic biology have deepened our understanding of the computational capacities of cellular components within complex networks. This genetic revolution has yielded extensive insights into molecular interactions, enabling the engineering of living systems by regulating cellular components, individual cells, and entire populations. However, control within these networks is not straightforward. While genes were once considered the primary agents of top-down regulation, metabolism is increasingly recognized as a bottom-up driver of change—allowing organisms to respond dynamically to local environmental fluctuations in real time (De Lorenzo 2015).

When viewed as assemblages, enlivened collectives can give rise to *unconventional forms of computation*—models that capture specific aspects of material dynamics. These include what Adamatzky (2009) describes as computing schemes whose time is either yet to come or already past, and what Stepney (2025) refers to as *persuadable matter* (Armstrong 2025). These systems operate through dynamics that include the formation of material "attractors" and hubs that catalyse flows of matter and energy across multiple spatial and temporal scales. Such agility and massively parallel processing capabilities are evident across a spectrum of monstrous liveliness—from particles and atoms to molecules, compounds, assemblages, cells, organisms, ecosystems, and the biogeosphere. These dynamic associations enable monstrous matter to maintain coherence while remaining highly responsive to environmental conditions (Tripaldi 2022: 18). This capacity for forming alliances is what grants enlivened matter its adaptability in the face of change. Dynamic material formations—such as the pulsatile, networked tubes of slime mould colonies (Adamatzky and Schubert 2014) or the vivid, fractal-like patterns of the Belousov–Zhabotinsky reaction, driven by electron transfer processes (Belousov 1959; Zhabotinsky 1964)—offer visual evidence of how metabolic networks extend through and around living systems. These phenomena illustrate how, under the right conditions, the computational capacities of lively matter can be observed at the macroscale, shaping material outcomes through distributed, emergent processes.

By interweaving the reductive abstractions of classical physics with the complex, context-sensitive dynamics of chemistry and biology, the relational nature of matter emerges as a *radically creative platform*. This synthesis links the biosphere with the human world, enabling a new understanding of material agency. The outcome of this unconventional integration—rooted in natural computation and emergent behaviour—defines the character of material change in the ecological era. It establishes the foundation for a new kind of design and engineering practice, one capable of rearticulating fundamental concepts

of life and intelligence. In doing so, it forges a coherent material continuum between nature and technology, opening pathways for more responsive and regenerative modes of engagement with the living world.

Microbial Alchemy

Theories about how an enlivened material world responds to change are diverse, yet they operate within a vast—though ultimately finite—range of possibilities. This finitude stems from the fact that matter always manifests locally, its behaviour shaped by specific environmental and contextual conditions. Even when the potential for transformation appears extensive, chemistry's capacity for parallel processing enables it to resolve multiple possibilities into distinct, observable material outcomes. While life resists entropy and enables complexity, its processes inevitably tend toward equilibrium and are not sustained indefinitely. This highlights the need for new frameworks to understand how matter can support persistent, creative change over time. Yet, under extreme conditions—such as at spacetime singularities or in environments where the known laws of physics and chemistry no longer apply—matter may behave so anomalously that it escapes recognition within the frameworks familiar to our solar system. These phenomena can only be observed indirectly, through astronomical instruments or particle accelerators like CERN, where matter behaves in ways that exceed our current conceptual and empirical grasp. Within the bounds of our material experience, we still lack a comprehensive, unified theory that integrates the diverse behaviours of matter without resorting to reductive simplifications. Presently, physics, biology, and chemistry offer distinct yet parallel lenses through which dynamic matter is understood. However, these disciplinary perspectives have yet to converge into a unified framework capable of fully accounting for matter's complexity and responsiveness. One way to navigate this conceptual fragmentation is to step outside the confines of human-centred knowledge and observe how other forms of life engage with matter directly.

Microbes, in particular, offer a compelling entry point. Free from the philosophical dilemmas and abstractions that complicate human inquiry, microbes simply *make matter work*. Their biochemical activities enact complex environmental regulation as proposed in the Gaia hypothesis (Lovelock and Margulis 1974), which is now being reinforced by modern discoveries in microbiology that reveal how microbial communities modulate atmospheric composition, nutrient cycles, and planetary homeostasis (Stolz 2017). Equipped with a versatile cytoplasmic toolkit, microbes perform extraordinary feats of molecular engineering: transforming raw substances into biologically valuable compounds, adapting to extreme environments, and driving processes at planetary scale. As Earth's most ancient life forms, microbes have shaped the biosphere since the dawn of life. For most of the planet's history, they were its only inhabitants, and today, with an estimated two to three billion species, they remain the dominant force in global biodiversity (Gwynne 2013). By studying how microbes manipulate matter—not through theory, but through action—we gain

a powerful means of checking our assumptions. Their behaviour invites us to deanthropocentrise our thinking and reconsider what it means to compute, adapt, and transform in a material world.

Microbes are the unseen engines of Earth's life-support system, performing extraordinary material transformations that keep the cycles of life turning. Without their constant activity, entropy would gain ground far more quickly—organic matter would accumulate, nutrients would stagnate, and the planet would edge toward lifelessness. Instead, microbes decompose dead organisms, upcycling their components back into the soil, where they become raw material for new life. This regenerative process ensures that even in death, bodies are reintegrated into the biosphere, fuelling future metabolic activity. Through their metabolic versatility, microbes drive the biogeochemical cycles that sustain life—recycling nutrients, producing essential gases like oxygen, carbon dioxide, methane, and nitrous oxide, and transforming inert matter into bioavailable forms. These processes are not random; they are coordinated through sophisticated chemical signalling systems, such as quorum sensing, where molecules like autoinducers regulate gene expression and synchronize collective behaviour (Miller and Bassler 2001). This enables microbial communities to perform complex tasks—swarming, cooperating, and secreting enzymes that break down organic material—ensuring that matter is continuously reactivated and repurposed. With the advent of metagenomics, it is now understood that microbes inhabit virtually all environments as interconnected ecosystems known as microbiomes. Their networked actions can decompose a whale carcass, fertilize forest soils, cause tooth decay, or illuminate ocean waves with bioluminescence. The biochemical space in which these interactions occur has been described as a "microbial commons," foundational to life and ecological balance. Lynn Margulis' interpretation of the Gaia hypothesis emphasises microbes as the primary agents driving elemental cycles—vital processes that maintain planetary health and possess the capacity to shape entire worlds (Lovelock and Margulis 1974). Without these microbial feats, Earth would resemble the barren landscapes of its planetary neighbours.

Despite their essential role in sustaining life, microbes are not inherently benevolent. Their remarkable adaptability—the very trait that makes them such creative agents of transformation—also makes them formidable opportunists. A small subset possesses pathogenic potential, not out of malice, but as an extension of their evolutionary drive to exploit available niches. To microbes, humans are not exceptional—we are simply another nutrient-rich environment to be explored and, if possible, exploited. Their opportunism is not malicious but evolutionary: microbes are constantly seeking new sources of energy and matter, and in doing so, some become pathogenic, causing disease in humans, animals, and plants alike. This dual nature—creative and destructive—is what makes them both vital and dangerous. When microbes were first observed in the seventeenth century by Robert Hooke and Antoni van Leeuwenhoek, they were met with wonder and curiosity (Gest 2004). But by the nineteenth century, the work of scientists like Louis Pasteur and Robert

Koch had revealed a darker side: specific microbes were responsible for devastating diseases such as tuberculosis and cholera (Gossel 2000). This shift in perception—from marvel to menace—continues to shape how we engage with microbial life today. Although scientific inquiry has illuminated much about microbial behaviour, full control remains elusive. Their ability to transform matter and energy into biologically valuable substances is astonishing, but it also makes them unpredictable. Pathogenic microbes are especially dangerous because of their invisibility and ubiquity. Their stealth and global reach render them a form of "monstrous matter"—simultaneously essential to life and capable of threatening it. This paradox demands a careful, ethically grounded approach to working with microbial life. As we seek to harness their capabilities for human and planetary benefit, we must do so with humility—recognizing their complexity, respecting their autonomy, and acknowledging that we are not outside the systems they shape, but deeply embedded within them.

Part 2: Ecological Technological Platforms: Applying the Synthesis to Regenerative Design

> *"If we are to survive, a new balance must be found. In normal times, evil would be fought with good. But in times like these, well, it should be fought by another kind of evil."* (Twohy et al. 2004)

Mechanistic approaches to the climate emergency are fundamentally ill-suited to address the crisis—because they are, in large part, its cause. Grounded in a worldview that treats matter as inert and lifeless, these systems extract energy from living and non-living sources alike to impose control, predictability, and efficiency. This logic has driven centuries of industrial development, but it has also led to widespread ecological degradation and the devitalisation of the planet. Mainstream responses—such as "net zero" initiatives—often replicate this same extractive mindset, offering scaled-down versions of the very systems that created the problem. As Albert Einstein famously suggested, we cannot solve a problem with the same thinking that created it. To meaningfully engage with the unruly, living materiality of the climate crisis, we must adopt a radically different perspective—one that recognizes matter as active, relational, and capable of transformation beyond mechanistic control (Black et al. 2021). What is needed instead is a mode of engagement that embraces complexity, unpredictability, and the distributed agency of "hyperobjects" (entities so vast in time and space, like climate change or plastic pollution, they can never be fully grasped or directly perceived by humans; who only ever experience their local effects (Morton 2010: 1, 13)—an approach that generates qualitatively different outcomes. Microbes offer a powerful and under acknowledged technical platform for this transition. Existing largely in highly distributed collectives, (Penesyan et al. 2021), they qualify as hyperobjects, where their capacity

to perform work—transforming matter and energy across a vast range of substrates, including those toxic or inaccessible to humans—makes them uniquely suited to operate in environments where conventional technologies fail. They thrive in extremes, metabolize waste, purify water, enrich soil, and clean the air. This is not the work of machines, but the *work of life* itself: regenerative, adaptive, and deeply entangled with the biosphere (Armstrong 2024a). If we are to restore rather than devitalize the living world, we must learn to collaborate with this microbial labour. To do so requires imagination—an ability to *recognise* microbes not as tools in the industrial sense, but as living systems whose metabolic processes can be guided, cultivated, and integrated into human infrastructures. Their "technology" is not mechanical but biochemical, ecological, and relational. Through their electron transfer systems, metabolic pathways, and chemical signalling, microbes compute and act upon matter in ways that are both precise and profoundly contextual. For example, electrogenic microbes can be cultivated on electrodes, producing electrons that generate bioelectricity and serve as digitally readable signals (Potter 1911). These outputs reflect microbial vitality and offer a direct interface between living systems and technological sensing. In this context, microbial demonstrators become more than scientific curiosities—they are living proofs of concept for a new kind of technology, one that aligns with the rhythms of the biosphere rather than working against them. They invite us to rethink what it means to engineer, to calculate, and to deal with a world in flux.

My ongoing research investigates the dynamic materiality of living systems—specifically their capacity to regenerate matter, enliven it, and respond to change—while also serving as a living laboratory where real-time events can be observed, analysed, and re-theorized. Central to this inquiry is the microbial platform, whose foundational role within the biosphere positions it as a transactional system that underpins life itself. This system can be understood as a kind of "economy," not in the modern financial sense, but in its original etymological form: *oikonomia*, from the Greek oikos (household) and *nemein* (management or dispensation), referring to the stewardship of shared resources (Lesham 2016). Building on this interpretation, I have situated my research within the infrastructure of household utilities—reframing the domestic sphere as a site of ecological and material transformation. Here, everyday practices become opportunities for citizens to engage directly with microbial life, enabling a transition from passive consumption to active participation in regenerative processes. This approach not only decentralises resource production but also reimagines the home as a dynamic interface between human and microbial economies.

Microbes as Technological Platforms

This approach aims to establish qualitatively different platforms for human development—distinct from industrial modernism—by harnessing the dynamic capabilities of life. In this model, citizens feed organic waste to microbes,

which in turn metabolise and transform it into biologically valuable resources such as soil enhancers or green energy. This domestic-scale exchange loosens the grip of commercial markets on everyday life, empowering citizens to become co-producers of resources in partnership with microbial life—simply through routine activities like eating, washing, grooming, and abluting. Contrary to the modern cultural paradigm that demands sterility—reinforced by the liberal use of antimicrobial agents (Domestos 2024)—a "living" household is characterized by its unique microbial colonies: a gardened, household-scale microbiome. These microbial communities naturally thrive in indoor environments, where people in Western cultures spend 90% of their lives (Mannan and Al-Ghamdi 2021). Situated microbial technologies allow citizens to shape the microbiome of the built environment (National Academies of Sciences, Engineering, and Medicine 2017), where bioreactors, walls, and surfaces host micro-worlds that actively regenerate the biochemical landscape of domestic interiors. Our understanding of this household microbial biosphere is still emerging (Leung, Tong, and Lee 2019).

The following case studies—*Living Architecture*, *Active Living Infrastructure: Controlled Environment* (ALICE), and *Microbial Hydroponics* (Mi-Hy)—are European Union-funded projects that explore microbial communities as active agents in electronic sensing, digital computation, material transformation, and the broader technology of life. Each initiative aims to establish household-scale ecosystems capable of transforming and valorising domestic waste streams through microbial bioremediation. These processes yield valuable outputs such as bioelectricity, organic sludge, and bespoke biomolecules, contributing to an integrated vision of the household as an ecosystem of enlivened material exchanges embedded within domestic infrastructure. At the core of these platforms are electrogenic biofilms that generate bioelectricity—serving as a usable product and also as a material and epistemic agent. This bioelectric output provides a tangible measure of the circular economy at work. It enables the evaluation of a household *oikonomy*—a regenerative system grounded in microbial activity that repurposes waste into input, mimicking ecological cycles and transforming the home from a site of obligate consumption into a biologically productive hub of useable resources. Each case study engages with "living" technical platforms composed of microbial and electronic components, seamlessly integrated through electron flows that invite new forms of cohabitation with the living realm—forms that are, in essence, world-making. By converting household waste into vital exchanges—such as energy and material resources—these microbial systems exhibit characteristics typically associated with life: sensitivity, metabolism, and even forms of distributed intelligence. Their inherent liveliness raises ethical considerations, prompting the development of protocols of care and co-inhabitation enacted through everyday household rituals. These rituals transform the impacts of human habitation into life-promoting actions. Functioning as a form of technologized soil, microbial technologies infiltrate domestic spaces through symbiotic relationships, forming an extended, gardened household microbiome (Kembel

et al. 2012). Embracing human presence while decentring it within broader ecological processes, these platforms interrogate the potential for alternative economies and household ecologies—ones better equipped to meet the environmental and social challenges of the twenty-first century.

Living Architecture

The Living Architecture project (Living Architecture 2019; Armstrong et al. 2017), funded by the European Union (2016–2019), explores the integration of microbial communities into architectural infrastructure through the development of a freestanding, next-generation, selectively programmable bioreactor. This system is composed of modular building blocks—microbial fuel cells (MFCs), algae photobioreactors, and genetically modified microbial processors—that function both as bioreactors and as standardized architectural units or "bricks" [Fig.1]. Microbial activity is "programmed" by spatially sequencing these modules, allowing the system to operate as a form of metabolic computation. Depending on the inputs, the system transforms substances through a series of biochemical reactions, effectively functioning as a metabolic app. The core hardware of the wild-type modules is based on the MFC, which includes an anode, a selective membrane, and a cathode. This configuration captures electrons generated by the bioelectrical activity of microbial biofilms, producing small but usable amounts of bioelectricity. The MFC can be conceptualised as an extended microbial "brain," processing biochemical information from nutrient-rich waste streams that enter through the anode—its "stomach"—and pass through a semi-permeable membrane—its "gut wall"—made of carbon fibre or ceramic. During this process, the MFC not only generates electricity but also cleans water and produces other metabolites. The electrons—described as quantum excreta—are harvested via conductive wires, optimized by artificial intelligence, and visualized through electronic interfaces (*see ALICE*). The algae photobioreactor is connected to the cathode, where it supplies oxygen as a by-product of photosynthesis, enhancing the bioelectrical output of the MFC by serving as a terminal electron acceptor. The entire system is coordinated by an artificial intelligence that monitors electricity production and dynamically adjusts inputs to optimize performance. Fed by domestic waste streams such as urine and greywater, along with air and sunlight, the microbial populations metabolize these inputs into a cascade of useful outputs. Each bioprocessor passes its metabolic by-products to the next module in the sequence, enabling a chain of transformations that mitigate the environmental impacts of human habitation—removing pollutants, generating electricity, synthesizing biomolecules, and recovering water. Human interaction with the system occurs at electrical, physical, and chemical interfaces, establishing a metabolic trading system. In this way, Living Architecture enables an interdependent relationship between humans and microbes, wherein the microbiota of human inhabitants becomes part of the nutrient stream, integrating them into the full operating "living" system. As this relationship deepens through habituation,

the system begins to function as a holobiont (Gordon et al. 2013). Importantly, the microbial populations are not artificially imposed but self-organize within the bioreactor environments, forming consortia and biofilms like those found in natural plumbing systems. Inhabited through daily rituals and practices of care, Living Architecture not only computes material flows but also exemplifies an alternative paradigm for domestic economies—transforming everyday human activities into world-making actions.

Figure 1. Living Architecture "wall", courtesy of the Living Architecture project, 2019.

As the original Living Architecture system incorporated genetically modified organisms, it could not be made directly accessible to the public. In response, an alternative wild-type prototype titled *999 Years, 13sqm (The Future Belongs to Ghosts)* was developed for the *Is This Tomorrow?* exhibition at the Whitechapel Gallery, in collaboration with artist Cecile B. Evans (Whitechapel Gallery 2019; Bevan 2019). This installation took the form of a speculative future apartment, a methodology that explores possible futures and challenges dominant paradigms by imagining alternative systems and realities. It housed a screen-based system powered by natural anaerobic biofilms embedded within an array of "living bricks" (Armstrong 2024b). The work provided a conceptual and material context for microbial infrastructure, envisioning a post-modern future shaped by the intersecting challenges of big data, bioengineering, and climate change. Within this imagined domestic space, a posthuman "household," which challenged human-centered thinking and emphasised the agency of nonhuman entities and distributed intelligence, was sustained by microbial metabolisms, while the only traces of human presence were digital ghosts—representations of past, present, and future inhabitants [Fig.2]. The installation offered a speculative framework for rethinking domestic life, where microbial technologies and digital systems converge to support new forms of ecological and existential continuity.

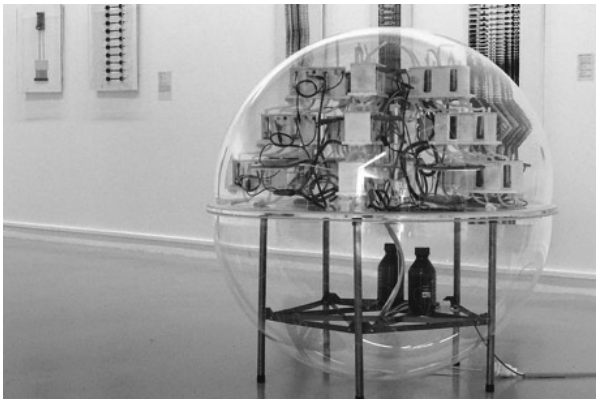

Figure 2. 999 years 13 sqm (the future belongs to ghosts). Photograph courtesy Rolf Hughes, 2019.

Active Living Infrastructure: Controlled Environment (ALICE)

While Living Architecture establishes a metabolic economy for transactions between humans and microbes, the *Active Living Infrastructure: Controlled Environment* (ALICE) prototype (2019–2021) lays the groundwork for more direct collaboration with microbial life (ALICE 2021). In this system, electrons produced by anaerobic biofilms within Microbial Fuel Cells (MFCs) are used as "data," creating a direct interface between bacterial metabolism and electronic systems capable of interpreting and visualizing microbial activity. This bacterial data embodies a unique form of environmental intelligence, offering insights into the character of a place and enabling a technologized, communicative interface between humans and microbes. Traditionally, microbial behaviour is interpreted through biochemical assays, a process that is often slow and abstract from a human perspective. By contrast, tapping into the rapid electron flows within biofilms allows for real-time understanding of microbial dynamics. Depending on the sensitivity of the electrodes, this approach opens the possibility of developing a responsive communication platform between humans and microbes [Fig.3]. In ALICE, the electrical activity of the biofilm serves as both a power source and a data stream. This data is translated by software into animations that visually convey the biofilm's status in accessible, human-readable terms. Rather than confronting users with the often-unappealing appearance of microbial colonies, the system presents microbial behaviour through engaging, screen-based interfaces. Participants can interact with the microbes in playful, exploratory ways—akin to caring for a houseplant or pet. This interface introduces the concept of "Mobes"—a term coined to describe the data-based, characterful representations of microbial life. Mobes offer a simple, probiotic approach to interspecies communication, making microbial behaviour relatable and potentially integrating it into everyday routines [Fig.4]. By promoting a conversational rather than exploitative

relationship with microbes, ALICE encourages a mode of learning-with microbial systems. These interactions reveal shared concerns—such as transforming waste into resources—and invite new forms of domestic labour and value creation grounded in ecological reciprocity.

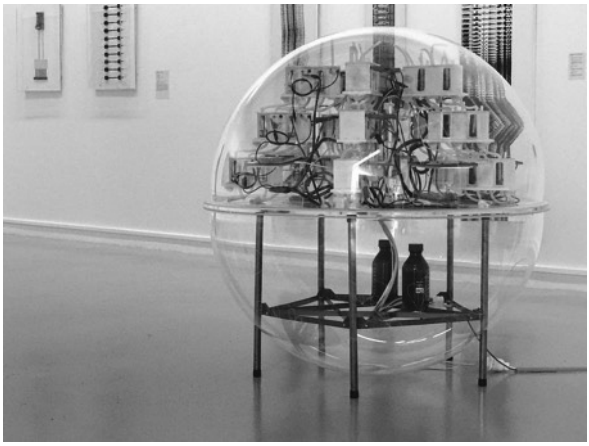

Figure 3. ALICE featured at the Dunkirk Triennale, 2023. Photograph courtesy the ALICE consortium, taken by Rachel Armstrong, 2023.

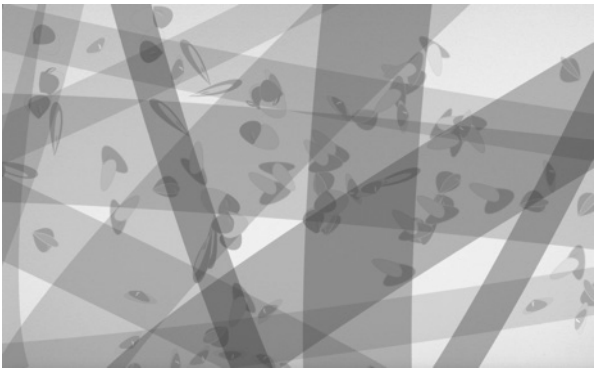

Figure 4. "Mobes"—electronic signals from microbial biofilms translated into graphical symbols. Artist Julie Freeman (see https://mobes.alice-interface.eu). Courtesy of the ALICE consortium, 2024.

Microbial Hydroponics

Having established the holobiontic principles of designing with microbial systems, the next step was to expand the range of participating biological and technological actors to enhance the system's self-sufficiency. In many modern urban contexts, households lack access to land and, consequently, the ability to produce their own food—conditions that reinforce exploitative and extractive living practices. The Microbial Hydroponics (Mi-Hy) project was developed

to address this challenge by integrating hydroponic food production with microbial communities, using only carbon dioxide, light, and household greywater as inputs [Fig.5]. Mi-Hy's key innovation is the creation of a *prosthetic rhizosphere* for hydroponic plant roots—an engineered microbial community inspired by the natural symbioses between plants, fungi and bacteria. In soil ecosystems, such microbial partnerships enable plants to convert carbon into biomass by optimizing nitrogen uptake and supporting the synthesis (the process of building complex structures from simpler components) of chlorophyll and amino acids. Hydroponically grown plants, however, typically lack these microbial allies and are thus dependent on synthetic fertilizers, which are inefficiently absorbed and often contribute to environmental degradation. Mi-Hy addresses this limitation by embedding designed microbial communities within two types of bioelectrochemical systems: Microbial Fuel Cells (MFCs), which generate bioelectricity, and Microbial Electrolysis Cells (MECs), which use surplus electricity from the MFCs to synthesise valuable biomolecules. These include 2,3-Butanediol—a precursor for bioplastics—and acetate, a versatile feedstock used in the production of chemicals, textiles, food products, and pharmaceuticals. The prosthetic rhizosphere housed within the MFC/MEC complex supports plant growth while reducing atmospheric carbon dioxide, generating bioelectricity, and producing nutritious biomass alongside programmable biochemical outputs. This microbial "black box" is adaptable to the needs of specific plants, with functions that can be designed and imported into the rhizosphere to meet targeted goals. In essence, Mi-Hy functions as a highly specialized microbial garden [Fig.6]. Like all gardens, it must be cultivated in relationship with its surrounding community. Mi-Hy's innovations thus extend the principles of holobiontic design, fostering a healthy, sustainable, and nature-based circular home environment where human occupants play an active role in building and maintaining diverse ecological communities.

Figure 5. Microbial Hydroponics, plant preparation, University of Southampton, UK. Photograph courtesy the Microbial Hydroponics consortium, taken by Rachel Armstrong, 2024.

Figure 6. Microbial Hydroponics, integration of hydroponics and MFCs, University of Southampton, UK. Photograph courtesy the Microbial Hydroponics consortium, taken by Dibyojyoty Nath, 2024.

Towards a New Mythos of Matter

A new mythos of matter for the twenty-first century must embrace its monstrous character and requires a rethinking of rigid classifications and laws to become more like guidelines for observations than decrees, so that it is possible to understand specific aspects of matter while also embracing its inherent complexity and unpredictability. This mythos, born of Gaia and EES, proposes a theory of life founded on commonality through diversity. To engage with it, we must deanthropocentrise our perspective, defamiliarising the material realm until it becomes strange again—until we see its monstrous, irreducible vitality. Our inherited frameworks—shaped by centuries of human thought—often obscure as much as they reveal, leading us to pursue the same well-worn paths even when they no longer serve us. To truly address the complexity of the climate and ecological crises, we must cultivate systems that allow us to see, feel, and experience the world differently—without the filters of anthropocentric bias or the reductive habits of mechanistic reasoning. By engaging with the dynamic materiality of life, it is possible to develop a deeper understanding and appreciation of the interconnected processes that sustain our world. Solving the challenges we face today cannot rely on thinking alone.

Our inherited frameworks—shaped by centuries of human thought—often obscure as much as they reveal, leading us to pursue the same well-worn paths even when they no longer serve us. To truly address the complexity of the climate and ecological crises, we must cultivate systems that allow us to see, feel, and experience the world differently—without the filters of anthropocentric bias or the reductive habits of mechanistic reasoning. This means developing ways of engaging with matter that are not only analytical but also perceptual, relational, and open to its monstrous strangeness. This strangeness is not an obstacle but the key. While our human lens is adept at dissection and description, it often fails to devise platforms for engagement that don't reduce this enlivened complexity. Embracing the monster unlocks new forms of thinking, observing, and ultimately, collaborating with matter itself.

Microbes are uniquely positioned to help us reimagine our relationship with matter. Their ancient metabolic processes and ongoing contributions to Earth's biosphere are expert in managing the flow and transformation of matter—building soil, purifying water, cleaning air, and metabolising waste, often in environments inhospitable to humans. Their biochemical versatility enables them to perform complex transformations using a wide range of substrates, including those that are toxic to humans. Through their direct engagement with molecular and even quantum processes, microbes navigate and influence the intricate web of material interactions that underpin life. This makes them a powerful technical platform—if we are imaginative enough to understand how to collaborate with their capabilities.

By deploying microbial metabolic and electron transfer systems through technological platforms, we can create *living technologies* that engage in dynamic reciprocity with matter—sensing and responding to molecular-level changes in real time. Unlike conventional systems that disrupt natural cycles, microbial operations are inherently part of them, offering a transformative model for addressing environmental challenges. This paradigm shift is exemplified in experimental initiatives such as Living Architecture, ALICE, and Microbial Hydroponics, where microbes are not treated as contaminants but embraces as vital collaborators in the built environment. These projects reconceptualise habitation as a co-productive process, integrating microbial agency into the flows of energy, waste, and resources. In doing so, they valorise waste, guide resource distribution, and enable regenerative processes. Microbial systems in these contexts generate data attuned to material conditions and produce outputs aligned with biospheric rhythms. Such innovations preserve the complexity and adaptability of microbial life, paving the way for sustainable and imaginative trajectories in human development—where our activities are embedded within, rather than imposed upon, the ecosystems we inhabit. This repositions humans from passive consumers to active participants in ecologically attuned systems.

However, employing microbes as a technological substrate requires an ethics of care (De La Bellacasa 2017). Their habitats and physiological needs must be respected and maintained—not as an afterthought, but as a foundational

principle. In this way, microbial technologies can offer functional solutions as well as a philosophical reorientation: a means to restore, rather than exhaust, the living systems we depend on—molecule by molecule.

Decentring the human perspective and situating ourselves within a broader ecological framework enables a richer understanding of the microbial scale—its intricate roles, adaptive capacities, and transformative potential. This is not a departure from scientific rigour, but an expansion of our epistemological toolkit: embracing observation, experience, and empirical engagement alongside abstract theory. As material events unfold—shaped by site-specific conditions and contextual nuances—multiple perspectives on matter converge, revealing its capacity for radical transformation. Latour's notion of Gaia as a monstrous entity offers a compelling framework for this transition through the possibility of monstrous matter: unpredictable, generative and deeply entangled with life. This metaphor transcends conventional scientific boundaries, making space for imagination, wonder, and the unexpected—while keeping matter firmly within the realm of rigorous inquiry. From this empirically grounded yet creatively open vantage point, new approaches emerge that bridge scientific investigation with imaginative exploration. Such a perspective calls for a *material ethics* of practice—one attuned to change, complexity, and the possibility of guided evolution. It urges us to design spaces for transformation through negotiation, and care, resisting the pull toward static equilibrium. By integrating storytelling, biosynthesis, bioremediation, and advanced scientific theory, we can cultivate a more enduring relationship with the dynamic materiality that surrounds us.

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Rejčel Armstrong

Monstruozna materija: mikrobne osnove za živu planetu

Apstrakt

Kako bismo se suočili sa rastućom klimatskom krizom, neophodan je novi, dvadesetoprvovekovni mit o materiji—onaj koji prevazilazi ekstraktivne, industrijske paradigme modernosti. Ovaj nastajući pogled na svet usredsređen je na koncept „monstruozne materije": neukrotive, dinamične materijalnosti života koja izmiče kategorizaciji, a ipak potpuno deluje u okviru zakona fizike i hemije. Ova materija svoj krajnji izraz nalazi u Gaji—ne kao harmoničnoj celini, već kao dinamičnoj, disruptivnoj pregovaračkoj igri između živih i neživih sila na planetarnoj skali. Umesto da bude haotična ili bez zakona, ova materija je duboko kreativna, budući da je upravo ona stvorila ogromno biodiverzitetsko i materijalno bogatstvo Zemlje. Prihvatanje ove perspektive poziva na prelazak u ljudskom razvoju—od kontrole i eksploatacije ka regenerativnim praksama koje se usklađuju sa prirodnim ciklusima promene i obnove. Arhitektura, kao materijalna i kulturna praksa, ima ključnu ulogu u ovoj transformaciji. Projektovanjem u skladu sa vitalnošću monstruozne materije—odbacujući krute geometrije i inertne materijale—arhitekte mogu stvarati okruženja koja podržavaju život, prilagodljivost i ekološki procvat. Ovaj mit nudi nadu i imaginativni okvir za ponovno promišljanje našeg odnosa prema živom svetu.

Ključne reči: monstruozna materija, Gaja, isprepletenost, materijalna agencija, mikrobi, nekonvencionalno računanje, metabolizam, holobiont, upravljanje prirodnim resursima, materijalna promena