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The silent harmony between machines, Sapiens, and the ecosystem: visions for a supportive and sustainable technological constituent

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Abstract

Digital sustainability represents an emerging paradigm that necessitates a critical reassessment of the relationship between technological advancement and socio-environmental preservation. Innovation can no longer be driven solely by logic centered on efficiency or profit. Instead, it must be embedded within a forward-looking vision where every design choice accounts for ecological and social repercussions. At the software level, this entails promoting languages and architectures capable of minimizing energy consumption while prioritizing applications that incentivize sustainable behaviors. Regarding hardware, the challenge lies in developing devices designed for longevity, ease of recycling, and low energy impact starting from the production phase. As digital infrastructure expands pervasively and generates increasing natural resource consumption, adopting systemic design strategies remains urgent. Such an approach transforms technical efficiency into a vehicle for environmental responsibility. Only through this strategy can digital technologies become a functional ally in the global ecological transition.

Keywords: Environmental and Digital Sustainability, Proactive Governance, Accountability, Coherent Digital Integratio

INTRODUCTION

The Anthropocene marks the transition from history to hyperhistory (Zalasiewicz at al., 2019) and represents the mature phase of a transformative process initiated long before the advent of computer science. It does not constitute a paradigmatic shift (Kuhn, 2009) emerging suddenly within human evolution. Rather, it is the culmination of a lengthy cognitive and technical trajectory through which humanity has sought to externalize thought by developing tools to mediate the relationship between sensory experience and rationality. Language, writing, and numerical systems function as the earliest cognitive infrastructures that expanded the reach of the imagination and organized worldly chaos into comprehensible forms well before electronic circuits. A continuity unfolds from Mesopotamian clay tablets to abaci used for calculation, and

from ritual inscriptions to contemporary algorithms capable of generating sounds, images, and texts. This progression refutes the idea of the digital revolution as a radical rupture. It appears instead as the final movement of an evolutionary process that began when ancestors entrusted memory to external supports and transformed intelligence into a distributed phenomenon (Ourednik, 2025). Human action now possesses the capacity to impact biospheric equilibria and shape its destiny through technical-artificial extensions. This development triggers an immediate crisis in the concept of religion, which yields its historical role as the guarantor of a future vision to technology. Such absorption into technical processes reveals the ancient nature of the entanglement between these two dimensions (Signorelli, 2025). The need to rethink political and legal categories arises from the obsolescence of interpretative models based on the dichotomy between subject and technique. These models prove insufficient for framing new regimes of attribution and responsibility. Within this framework, the algorithmic infrastructure can be configured as the product of a collective intelligence transcending individual subjectivity. It integrates into decision-making processes where the machine assumes the role of a structural factor of power and necessitates a radical revision of social and economic protection mechanisms. Algorithms in this context are no longer perceived as mere executive instruments but as entities endowed with an operational autonomy that profoundly affects power structures and the economy. This functional emancipation impacts the entire biosphere and suggests a constitutionalism that overcomes past normative fragmentations. Such an approach reunites the technosphere and the biosphere within a unified horizon where every component contributes to a systemic balance capable of addressing the global ecological crisis by transcending traditional anthropocentric views. Drawing on the synergy between posthuman thought and techno-legal analysis, the proposal advanced in this essay highlights the new interdependencies between the physical and digital worlds while promoting shared responsibility for collective well-being. The technological revolution described here sheds traits associated with alienation or wild disruption (Tanni, 2025). It assumes the role of a constant and meaningful connection between individual action and the surrounding ecosystem. This shifts innovation toward an extended and structural sustainability that moves beyond paradigms founded on absolute anthropocentrism and the rigid separation between human subjects and technical apparatuses. The digital thus abandons its instrumental nature to integrate into a systemic vision where technology represents an essential component of the biosphere. This proposed methodological path allows theoretical reflection to expand by including technical-scientific, anthropological, ethical, and cultural aspects such as data altruism. It opens the way for a revision of the core of institutions and decision-making processes so they may adapt to the challenges of contemporary complexity. A rethinking of the near-term horizon in light of transparency and regeneration appears unavoidable. Technological progress must intertwine systemically with ecological balance (Barry, 1999) and social justice. Traditional human-machine dichotomies lose meaning and give way to a relationship of co-agency where human and artificial agents co-evolve and produce interconnected social and environmental effects. Fully realizing this potential requires structured governance based on rules, standards, and accountability procedures. These mechanisms must guide technological innovation toward sustainable and inclusive results to avoid hyper-regulative drifts that could destabilize the entire biosphere (Shananhan, 2015).

EVOLUTIONARY PATHS OF A PARADIGM: FROM EARLY CYBERNETICS TO THE RISE OF COMPUTATIONAL ECOSOPHY

The roots of the concept of algorithmic sustainability lie in a prolonged process of disillusionment with the linear and deterministic models that guided digital technology design for decades. During the early 2000s, the initial confidence in algorithms as predictive and optimizing tools began to erode, eventually collapsing during the 2008 financial crisis. In that instance, the very algorithms intended to ensure stability and control became active agents of systemic failure. This event exposed the profound limitations of understanding technology through the illusion that worldly complexity could be reduced to mere statistics or models. Subsequently, a growing need emerged to radically revise the categories used to interpret technological progress and the entire computational framework. Within this context, the legacy of second-order cybernetics returned to the fore. This perspective, developed in psychology between the 1960s and 1980s, challenged the principle of separation between the observer and the observed system (Foerster, 2004) by proposing a paradigm of open systems capable of self-organization and evolution (Bateson, 2023). These ideas found new vitality in the recent evolution of neural architectures, particularly deep learning. Today, discussing machine learning—notwithstanding the semantic limitations the expression embodies—refers to deep adaptive processes. In these processes, the system learns autonomously and continuously modifies its internal configurations in response to data and the interacting environment. It co-evolves with its surroundings through techno-genesis, redefining its own structure over time. Algorithms are no longer viewed as autonomous or separate entities. Instead, they constitute integral parts of a complex ecosystem comprising material infrastructures, environmental inputs, physical constraints, and interactions with other forms of human and non-human intelligence (Hui at al. 2016). This demonstrates how the digital realm exists within the natural world as one of its most interdependent expressions. Fully digital and autonomous life forms, such as Intelligent Agents, are now recognized as new subjectivities present within the global environment (Onlife) (Floridi, 2015). They embody forms of radical alterity capable of forging physical reality and deeply impacting our self-understanding. They transform how we relate to ourselves and others while continuously redefining our interpretation of the world. Every expression of human agency is inevitably involved in and redefined by these emerging dynamics, leading to several profound implications. The first implication is that computational technologies must be reconsidered in terms of their physical limits, as they are neither immaterial nor infinite. Servers, data centers, mobile devices, and neural networks consume energy, require resources, and produce waste. Discussing algorithmic sustainability therefore means challenging the apparent neutrality of digital impact and acknowledging its ecological weight. The second implication concerns how the expansion of data centers and their increasing energy demands have begun to tangibly affect consumer costs. In the United States, households saw significant increases in electricity bills, with the monthly average rising from 114 dollars in 2020 to 142 dollars in 2025—an increase of nearly 25%. This impact was particularly pronounced in states with high concentrations of energy-intensive digital infrastructure, such as Ohio, where domestic utility costs jumped from 175 to 310 dollars per month, marking a 77% increase. In conclusion, understanding the digital phenomenon necessitates an epistemic paradigm based on anticipation and constant interaction, prioritizing proactivity over mere procedural reactivity. This approach outlines a theoretical horizon that moves beyond absolute anthropocentrism as a pillar of modernity. It allows technologies to be interpreted as active subjects capable of reconfiguring reality and participating in a complex system where the boundary between the natural and the artificial fades toward ontological and functional integration. Designing algorithmic sustainability requires a preliminary acceptance that human will and intention are only components of a larger system defined by principles of coexistence

and shared responsibility rather than absolute dominance. The 2008 financial algorithm crisis represented a cultural turning point that challenged the dogma of automation and prediction as the sole means of governing complexity. The rise of World Models, which surpass current Large Language Models, marks a crucial transition toward Artificial General Intelligence (AGI). In this phase, universal tokenization allows for a move beyond mere statistics toward a semantic understanding of concepts. In an era where computation has shifted from a neutral tool to a pervasive infrastructure, a crucial question arises regarding what form of knowledge remains possible and desirable. Since intelligence is no longer an exclusively human prerogative, algorithmic sustainability emerges as a necessary shift. It seeks to transcend mere technological refinement, preventing technology from consuming its own foundations while restraining the darker impulses of human nature.

FROM INDIVIDUAL LIABILITY TO COLLECTIVE CO-RESPONSIBILITY: A NEW NORMATIVE HORIZON

Every aspect of our daily existence is permeated by the increasingly audible presence of algorithms. These entities influence decisions in critical domains such as credit access, employment recruitment, social media content selection, and information distribution. Having established their non-neutrality, algorithms function as filters through which data is selected and presented. They shape individual and collective perceptions of reality while reflecting and frequently amplifying pre-existing inequalities. They perpetuate racial, gender, and socioeconomic biases even when these are masked by proxies, such as using postal codes as a substitute for high-density or marginalized neighborhoods (Crawford, 2021). The capacity of algorithms to profoundly influence social and individual dynamics raises significant ethical questions. Automated decisions, though appearing objective, can be opaque and difficult to contest, particularly when based on flawed historical data or non-transparent machine learning logics. The consequences transcend the impact on single individuals and affect society as a whole. Given this complexity, it is evident that no single actor—whether a developer, an institution, or a user—can unilaterally assume responsibility for the ethical and social implications of algorithms. The design and implementation of algorithmic systems require a shared vision and collaboration among diverse stakeholders to ensure that technologies are developed and utilized in a fair, transparent, and human rights-compliant manner. This context implies the necessity of placing the algorithmic question within the broader framework of sustainability, considering the capacity of computational systems to redefine power relations, citizenship models, and forms of responsibility (Coeckelbergh, 2020). Furthermore, a multi-level approach is required to recognize collective responsibility in algorithmic management. This approach must promote transparency, inclusivity, and accountability while adopting practices that consider social and ethical impacts. Integrating preventive evaluations and control mechanisms involving all stakeholders (distributed responsibility) is essential to reduce inequalities, biases, and unintended consequences. A clear environment has emerged where physical and digital entities coexist in a complex network of interactions. This necessitates an extension of the concept of responsibility beyond human boundaries, resulting in an ontological symmetry between the human and the non-human. Through the conceptual lens of posthumanism, one can observe how technologies—and algorithms specifically—act as agents within complex interaction networks. This marks the transition beyond the traditional anthropocentric conception that viewed the human being as the sole center of action and responsibility. Algorithms do not merely execute functions defined by programmers. They influence information flows, create new social dynamics, affect access to resources, and model behaviors. Consequently, they participate actively in the construction of social and cultural reality, assuming an agent-like role within the relational fabric shared by humans and algorithms. This new relational vision

implies that responsibility cannot be attributed exclusively to the humans who design or use these systems. Technology is no longer a mere external support but a co-constitutive element of cognitive and social processes, as suggested by material engagement theory (Malafouris, 2019). Technological governance must acknowledge the complexity of interactions between human and non-human agents by developing transparent, shared practices that distribute responsibility collectively. Viewing algorithms as active parts of an ethico-social ecosystem makes the adoption of management strategies involving developers, institutions, and users a natural progression. In such a context, the Renaissance notion of *Homo faber* acquires renewed significance. Human beings are characterized by their ability to transform evolutionary paths, generating new material forms and opening unprecedented possibilities for interaction with the world. We construct ourselves through the creation and employment of tools that shape our minds, extend our bodily potential, and redefine our experience of reality. The things we produce, in turn, produce us. This dialectical process is even more evident today as new materialities and digital ecologies permeate daily life and deeply influence thought and action. The concept of *Homo faber* is thus reinterpreted. It retains the original emphasis on the primacy of making and the central role of creative material engagement in human evolution. Simultaneously, it is emancipated from excessively anthropocentric interpretations by recognizing that the technological tools we create are full participants in the construction of reality. Technological man, approaching the "singularity" (Kurzweil, 2024), is transformed by his works like his predecessors. However, the current "species leap" lies in recognizing these tools as co-authors of the real through a creative material engagement. This can be defined as a long-term commitment to discovering new varieties of material forms through a saturated and situated engagement of thought and feeling with the things and materials that generate form. Human awareness of the reciprocal determination between beings and technological objects invites a departure from reductive perspectives that view the man-machine relationship as unidirectional dominance. Within this framework, ethical reflection expands toward a dimension of co-responsibility where the boundary between creator and creature becomes permeable and dynamic. Responsibility moves beyond the individual developer or end-user to become a distributed phenomenon. The design, adoption, and management of technologies involve an entanglement of actions and decisions shared among developers, users, material infrastructures, and political institutions. This model of co-responsibility acknowledges that technological effects propagate through complex social, cultural, and political networks. It requires collective participation and a regulatory commitment capable of governing the opportunities and risks inherent in digital tools. Distributed responsibility thus becomes both an ethical principle and an operational paradigm for contemporary technological governance. Transparency and the protection of fundamental rights are achieved through cooperation and the active sharing of choices and consequences, rather than through vertical impositions or isolated control mechanisms.

THE FUTURE OF DIGITAL CONSTITUTIONALISM: FINAL CONSIDERATIONS

The analysis of algorithmic sustainability constitutes a broad conceptual and operational project. It challenges and restructures traditional paradigms of technological governance while opening the way for a new configuration of the technosphere as an autonomous global system (Haff, 2016). In this framework, law, technology, and the natural environment interact as interconnected components of a dynamic and resilient ecosystem. Such a perspective necessitates a revision of the epistemological and normative models that have historically separated technical action from legal and political spheres. It promotes a relational and systemic vision that recognizes the reciprocal determinations between human subjects, technological objects, and ecological contexts. Institutions, material infrastructures, and digital networks assume an active function in the co-production of ethical, social, and environmental outcomes.

This suggests the need for hybrid institutional ecologies where metabolic, regenerative, and circular logics serve as pillars for an equitable and sustainable future. The traditional vertical relationship between authority and liberty, characteristic of modern political structures, has been profoundly transformed by the digital era. This transition has introduced a horizontal dimension that redefines the relationship between the public good of political communities and the private power exercised by major information platforms. These platforms manage information flows and personal data while directly influencing the exercise of fundamental rights and democratic participation. Consequently, they act as entities endowed with a power that, despite being formally private, performs functions of public interest. Adherence to technology can no longer take the form of dogma. It is necessary to strip it of the messianic expectation that views it as a supernatural entity capable of permanently transforming human destiny. Today, the refusal to consider technology as an unquestionable source of truth or an absolute power structure appears as an indispensable critical act. When the technological imaginary demands absolute trust, one must deconstruct its premises of neutrality and challenge the logic of "single thought" by promoting a healthy skepticism that introduces moments of discontinuity to interrupt the automatism of consent. Digital constitutionalism and posthuman philosophies provide the interpretative keys to translate abstract principles into normative architectures capable of withstanding the impact of digital globalization and hyper-connectivity. In this scenario, law ceases to be an external constraint and becomes an intrinsic component of the technological system, engaging in a constant dialogue with code to ensure sustainable processes. Reconsidering algorithms as co-creators of ecological and social equilibrium—capable of simultaneously affecting resources, data, and fundamental rights—makes a co-foundational governance urgent. In this model, institutions and corporations jointly define policies and protocols. This synergy produces a new form of sustainability understood as an operational principle that integrates technical efficiency with equity and inclusion, transforming the complexity of reality into opportunities for robust decision-making models. The ecological technosphere project embraces this challenge to rethink the coexistence of progress and the environment. Drawing on the legacy of Beniamino Caravita, a seminal figure in environmental constitutionalism, this approach manifests as an articulated system of legal tools aimed at both the conservation and active regeneration of technological balance. Moving beyond mere compliance, this paradigm—supported by a rigorous digital constitutionalism—will coordinate economic interests and environmental protection within a vision of intergenerational responsibility. In this sense, the Aristotelian maxim resonates strongly, highlighting the unavoidable need to determine "what is right reason and what is the measure that defines it". This is a necessary act to safeguard the criterion by which every individual constructs their identity within the technosphere.

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