Appropriate Technologies: For Regenerative Practices and Ecological Citizenship, Yielding Planet-centred Design

Authors
Dr. Jeremy Keenan[1]
Dr. Luke Gooding[2,3]
Dr. Robert Phillips[1]

Institutions
[1]Royal College of Art (United Kingdom)
[2]Stockholm Environmental Institute (United Kingdom)
[3]York University (United Kingdom)

Abstract

This article examines how technologies could be reimagined not as instruments of extraction or control, but as entangled agents within ecological, social and infrastructural systems, capable of facilitating Ecological Citizenship. Authors critically analyze contemporary design-led technologies, illustrating a paradigmatic transition from extractive practices to regenerative methodologies. This work builds on a review of extant literature across disciplines of design, philosophy, cultural criticism and science, exemplified by a discussion of Ecological Citizenship technologies in practice. Examples span established case studies, pilot projects funded by the EPSRC (UKRI funding body), the broader domains of commercial production, academic research, ecological science and distributed local communities.

Rather than treating the ecological and technological as opposing forces, authors elaborate an integrated account of their entanglement towards the development of a methodology for designers, technologists, and citizens to engage with planetary futures through participatory, situated, and contextually appropriate practices. This review culminates in the *Ecological Citizenship Technologies Framework (ECT Framework)*, a conceptual tool for the analysis, design and distribution of technologies within an ecologically interdependent planetary context.

Keywords: Design with nature, ecological citizenship, more-than-human design, planetary conviviality, planetary infrastructure, reciprocal technologies, regenerative technology.

Introduction

The following discourse is situated within an integrated field of design, technology, and Ecological Citizenship, addressing audiences across design practice(s), design research, ecological practice and civic governance who recognize that technological infrastructures are ontologically inseparable from the ecological systems in which they operate. Its applicability lies outside the prescription of reductionistic solutions (Vian et al. 2023), proposing a mode of enquiry that recasts technology as an existential condition of planetary life, a constitutive force that coproduces ecological and civic realities on a planetary scale. This research scope pertains to designers, technologists, citizen activists, policymakers, and ecologically oriented practitioners seeking paradigms adequate to the demands of regenerative planetary action.

Authors primarily interrogate how technologies can be understood as infrastructures of Ecological Citizenship: how they might catalyze agency and autonomy without reproducing atomization, enact reciprocity without reverting to nostalgic naturalism, and remain responsive to emergent ecological conditions without collapsing into more facile implementations of techno-solutionist prescription (Sætra & Selinger 2024). The argument insists on a reconfiguration of technology as necessarily intrinsic with ecological processes, refusing the entrenched epistemological binaries that have historically positioned nature as passive substrate and technology as active agent (Alves et al. 2024). But this is not merely a move to mediation between pre-existing agents; technologies also produce an image of the world they interpenetrate, especially where sensors and climatic visualizations render long-term planetary phenomena, such as warming trends or land cover shifts, visible in ways human perception alone never could. Remote sensing systems, for instance, do not just transmit data: they mediate an Earth-image that shapes political imaginaries (Voordijk et al. 2024).

Ecological Citizenship Technologies (ECT) are therefore intrinsic within ecological processes, and their value supersedes efficiency as its sole measure. They are evaluated more by a capacity to negotiate ecosystemic interdependence and planetary conviviality: a condition in which technologies are designed and governed as relational agents which cultivate mutuality across human and more-than-human systems. This extends Illich's notion of convivial tools (Illich 2009) from the domain of human autonomy to the planetary scale of ecological interdependence. The article proceeds by tracing the conceptual genealogy of Ecological Citizenship technologies. This trajectory is extended through planetary design discourses (Akama et al. 2020), ecological epistemologies (Scheiner et al. 1993), and analyzes that understand technologies as instrumental, material artefacts as well as vehicles of existential change. Authors position ecological design as a mode of planetary practice, in which technological mediation is inseparable from the production of ecological knowledge and the expanded conditions of citizenship itself.

This orientation is demonstrated in implementations through which participatory biodiversity platforms such as eBird (Peterson et al. 2025) convert distributed observations into planetary governance data and position citizens as active epistemic agents of change. It is exemplified in community-based water monitoring projects where Indigenous practices conjoin with institutional systems, producing a polycentric citizenship that is both local, distributed and systemic (Rathwell, Armitage, & Berkes 2015). It is also notable in the work of environmental justice sensor networks in the *West Oakland Environmental Indicators Project* (West Oakland Environmental Indicators Project, n.d.), where the civic standing of residents is juridically transformed through the evidentiary force of community-deployed monitors (Sabin Center for Climate Change Law 2025). Taken together, these practices position citizenship not as a prescriptive category but as a technologically mediated condition, coincident with the very processes of ecological design and planetary conviviality they sustain. We summarize this perspective as: ***Sustainable Intentions >*** *The proposal initiation and intent is to build sustainable practices.*

Case studies, ranging from UKRI-funded pilot projects to international initiatives, function less as exemplars than as probes: they indicate the possibility of technologies that are non-extractive, designed in collaboration, catalytic of agency and autonomy, and contextually adaptive. The importance of these examples lies not in the instrumental objective of their outcomes but in their generativity: each demonstrates how Ecological Citizenship can be materially instantiated in technological form. Though the work is grounded in a UK perspective, (given the conditions of UKRI support), the articulated framework yields transferability. The ecological entanglements described do not recognize national borders, and the epistemological orientation advocates reciprocity and an intersystemic awareness that is inherently multiscalar and planetary.

Authors build from a set of interlocking precedents: ecological design traditions attentive to context and relation; epistemologies of ecology that prioritize entanglement and interdependence, theories of technology that recognize its existential force, and discourses of Ecological Citizenship that transfer responsibility from atomized consumers to distributed collectives across human and more-than-human domains. It is from this nexus that authors specify a framework, not as a rigid schema, but as a generative scaffold – an invitation to imagine technologies that are not simply instruments for human ends but existential conditions of ecological reciprocity.

For example, the Khasi and Jaintia peoples of Meghalaya (India), cultivate *Living Root Bridges* by guiding aerial roots of *Ficus Elastica* across streams and ravines. Over centuries, these bridges strengthen as roots thicken and interweave; a bridge is not constructed in a single cycle of design and deployment but lives, grows, and adapts with the local ecosystem across connected scales of time. These structures provide a connectivity of human flow while also contributing to slope stabilization, biodiversity corridors, and flood resilience (Ludwig et al. 2019).

This case demonstrates a technology that situates human ends as intrinsically connected to ecosystems and Ecological Citizenship: the root-bridge is a co-constructed human infrastructure that emerges in reciprocity with ecological growth. The *Living Root Bridge* constitutes an existential condition of ecological reciprocity by connecting human access, plant growth, hydrological cycles, and habitat support into a living infrastructural assemblage.

This case also suggests that the sole analytical axis of Ecological Citizenship Technologies cannot be reduced to 'low' vs 'high' technologies and exists as a constellation of values across more-than-human spans of time, capacities for repair, the promotion of regenerative growth, strategies conscious of decay, and the ethos of intersystemic cohesion. We summarize these insights as: ***Accessible >*** *Easy entry point(s), low friction interventions, could be inter-generational, considering its life over time.*

In this sense, the contribution of this article is to reformulate conventional understandings of technology itself: from an instrumental artefact to a planetary practice, a distributed epistemic agent through which ecological and civic futures are continuously negotiated. By repositioning design within the larger context of planetary kinship, by associating technology with reciprocity, and by understanding citizenship as inherently ecologically entangled, authors promote a discourse in which preferable futures may be enacted as processes of relational intersystemic coproduction across innately connected planetary spheres.

We position ourselves regarding the use of the term 'Appropriate Technology' in line with contemporary strands of extant discourses surrounding it that extend its anthropocentric roots (Tufarelli 2025). As this concept has conventionally focused on technologies tailored to human scale, social equity, and localised forms of empowerment (Bishop 2021; Clegg 1988), we endorse an interpretation that broadens this scope to include ecological systems and more-than-human forms of inclusion. From this perspective, technologies are 'appropriate' both when they meet human needs sustainably and when they cultivate reciprocal relations across environmental domains and multispecies ecologies. They are appropriate to their circumstances, duration, impact and are not shoehorned into conventional frames of high, or low…but suit their environment of delivery. For example, a nail chosen for timber frame construction over a screw, as it enables the building to move, is more durable and is cheaper.

Prevailing perceptions often depict technology as inherently oppositional to ecological sensibilities and behaviours. This perspective overlooks the entangled co-emergence of technological and ecological systems (Rakova et al. 2023). Challenging this binary opposition, our examination seeks a perspectival reorientation towards technology as integrated within Ecological Citizenship, suggesting a new mode of technological praxis embedded in its ecological and social contexts. This reorientation is further developed and articulated through specific design tools and principles, exemplified by case studies indicating preferable future trajectories for technology creation, deployment, and governance. By embedding regenerative principles into technological praxis, authors advocate a turn from anthropocentric operational efficiency to mutualistic planetary existence. Project signposting includes:

1. **The Citizens Air Complaint Programme**: incentivizing communities to actively report idling vehicles contributing negatively to local air quality.
2. **GainForest**: decentralized non-profit organization leveraging archival analytical methodologies for earth's ecological data, reinforcing transparent and inclusive environmental decision-making.
3. **AgLab**: enabling farms to produce low-carbon, plant-based insulation blocks using existing agricultural waste materials and equipment.
4. **Ecology of Things**: regenerative approaches to ecological-technological integration.

Central to these case studies are design principles characterized as:

1. Non-extractive
2. Created in collaboration not others
3. Designing for future ownership, governance and design for exit
4. Produced in considerate to its surroundings as is appropriate tech, not merely high tech

Ecological Citizenship

For the purposes of this article, Ecological Citizenship is understood as a mode of relational participation that converges across ecological, technological, and social fields. Initiatives such as the EPSRC-funded *Ecological Citizens(s) Network+* exemplify this approach – mobilizing communities of knowledge and practice that integrate environmental knowledge with civic agency. *Ecological Citizen(s) Network+* project EcoLandS equips communities with a digital platform to identify, claim, and collaboratively manage disused land for autonomous approaches to urban biodiversity, suggesting a more inclusive model of land governance in which communities, ecologies, and technological practices collectively organize local space in ways that shape and sustain emergent forms of Ecological Citizenship.

Given that broader discussions of citizenship as a function of sovereignty and state are outside the scope of this article, our use of the term resists narrow legal-or state-based definitions that confine citizenship to a framework of legislated rights and privileges. Instead, we draw on a more expansive and situated understanding, where citizenship is distributed across all living entities that participate in, and are affected by, the ecological and social dynamics of a place. This view resonates with Latour's proposition of a *Parliament of Things*, where more-than-human entities are recognized as active participants in shared worlds (Latour 2004).

Citizenship is thereby understood as a relational stake within a shared environment, an orientation that extends beyond the human to acknowledge multispecies and multisystem, multiscale interdependence (Donaldson & Kymlicka 2011; Dunkley 2023; Kymlicka & Donaldson 2014; Rupprecht et al. 2020). This form of citizenship is not exclusive but entangled: it exists across domains of human intentions, ecological processes, and technological mediation, redefining agency as collective, mutualistic, polycentric and distributed. As such, Ecological Citizenship implies a responsibility to more-than-human systems, situating ethical agency within ecological interdependence rather than juridical entitlement. This move reconfigures citizenship from a tiered package of negotiable rights into a set of duties rooted in and emerging from planetary kinship, reciprocity, and relational accountability.

We propose that Ecological Citizenship should not be an anthropocentric endeavor, and that this necessary feature represents a meaningful distinction from conventional categories of citizenship. Current discourses still often reflect the reproduction of 'human values', as with the discussion surrounding 'AI alignment' (Ji et al. 2023). As critics observe, AI alignment as conventionally conceived assumes the centrality of human preference and instrumental rationality, often suppressing more-than-human interests and ecological complexity. For example, Tan et al. (2024) critique prevailing 'preferentist' alignment frameworks that treat human preferences as the sole axis of AI ethics, ignoring value pluralism or ecological contexts (Zhi-Xuan et al. 2024). Korecki (2024) introduces the concept of *Biospheric AI*, arguing that an anthropocentric model of AI 'alignment' is insufficient and risks systemic harm by marginalizing biospheric concerns. A broader scoping review of AI ethics standards finds that anthropocentrism frequently marginalizes more-than-human animals and environmental well-being (Rigley et al. 2023). With this in mind, a focus on more-than-human ecologies and their entanglements across spheres of analysis (biosphere, technosphere) contextualizes our discussion of Ecological Citizenship as it pertains to discourses around anthropic decentring and its potential for the restructuring of technological praxis.

Phillips et al. (2023) describe Ecological Citizenship as comprising 'accessible activities and skills which establish sustainable practice(s) and/or address ecological inequalities,' emphasizing duties to ecosystems and communities over individual liberties. Spannring (2019) argues that Ecological Citizenship calls for a reorientation towards more-than-human domains, embedding strong relational obligations into civic identity. A parallel emerges in recent participatory design projects that elevate more-than-human stakeholders through ecological obligations. In one urban biodiversity initiative, designers developed a 'participatory ladder for non-humans,' inviting bees and plants into the design decision-making loop with tangible rights alongside human participants (Hernandez-Santin et al. 2023). This exemplifies a duty-based citizenship: humans are morally and materially obliged to shape environments in ways that sustain multispecies communities, not merely preserve human instrumental prerogatives. We also highlight the difference between 'participation' and 'engagement' where citizens are able to be actively involved in the work, moving into post-participatory modalities (Phillips & Ferrarello 2025).

This duty-oriented stance challenges conventional rights-based frameworks, where eviction of a species from an urban site might be legal but unethical within an Ecological Citizenship discourse. It compels designers to recognize and enact obligations toward nonhumans, making ecological accountability inextricable from design praxis. Ecological Citizenship extends normative environmentalism by prioritizing relational agency and multispecies responsibility within sociotechnical systems. As designers, we situate our practices within these systems, aiming not just to solve discrete problems but to reconfigure the relational ecologies that connect communities, technologies, and environments (Bauer & Herder 2009; Norman & Stappers 2015).

Authors question how technologies might be designed, distributed, deployed and governed to mitigate harm and actively support regenerative futures; what design principles (Raymond et al. 2025), epistemologies (Toner et al. 2023), and engagements (Richardson et al. 2016) could guide this reorientation? Ecological Citizenship concerns environmentally responsible behaviours individually and collectively, with an eye towards the reorientation of political and technological subjectivity, wherein citizenship is distributed across species boundaries, ecological systems, and infrastructural entanglements, affirming collective responsibility, interdependence, and relational agency within a mutually constituted planetary context. Ecological Citizenship offers a reorientation of agency that neither collapses responsibility into the atomized figure of the 'responsible consumer' nor abandons the possibility of effective action. It displaces the rhetorical burden of planetary repair from the individual as a self-regulating unit towards the individual as situated within ecological and infrastructural systems. In this sense, Ecological Citizenship invites modes of design that cultivate autonomy without reproducing the isolating logics of behavioural nudging (Schmidt & Engelen 2020) or reductive techno-solutionism (Jensen et al. 2021; Sætra & Selinger 2024). Projects like *GainForest* (Dao et al. 2019), which reconfigure data infrastructures as collectively governed ecological commons, or *AgLab* (LeadsOnTrees 2024), where the ecology of material cycles are redirected through localized agricultural knowledge, exemplify a recalibration of agency that is distributive, regenerative, and collaborative.

Conversely, carbon-footprint calculators and personal-offsetting apps, regardless of their theatre of empowerment, reinscribe the fantasy of sovereign individual action, presenting planetary-scale disruption as a ledger of lifestyle choices. Bird identification apps enable new sensory relationships with ecological domains, yet they risk incentivizing ecologically disruptive attention, collapsing ecological presence into gamified capture (Lundquist et al. 2025; Peterson et al. 2025b); this concern connects with broader critiques around the ethics of gamification that have pertinence to principles of Ecological Citizenship, particularly the potential for inhibition of autonomy (Klock et al. 2023).

The challenge for designers, then, is to engage with technology not as a neutral intermediary but as a constitutive force within interdependent planetary systems in ways that illuminate systemic entanglement, refuse moral outsourcing, and generate conditions for a collective reconstruction of technological praxis, with the aim of ensuring that communities can access it and have autonomy though it, and if necessary, from it. In this sense, the mutualistic production, deployment and use of a technology in context and the conditions it enables becomes a cooperative act of citizenship in itself. We summarize these perspectives as: ***Designed 'with, not for' >*** *Designed with people, openly in collaboration, not inflicted upon them.*

The Ecological Citizen(s) Technology Framework

The *ECT Framework* functions less as a rigid model than as a generative scaffold, capable of informing design, governance, and technological imagination. Its affordances lie in its openness: enabling iterative, participatory, and ecologically embedded engagements. Post-participatory design gives citizen(s) agency to manoeuvre and dictate outcomes rather than just 'attending' in another's vision of a proposition (Phillips & Ferrarello 2025) . It means that the work is edited at source and can enable new conversations, for citizens with citizens. Whether through prototyping speculative ventures or analyzing existing interventions, this toolkit repositions the locus of technological agency from extraction to relation, from optimization to planetary kinship.

This framework is deliberately open, scalable across contexts and disciplines. It functions not as a static schema but as a responsive interface for ecological engagement. Its main affordance is to render visible the relational and systemic dimensions of design, prompting reconsideration of assumptions about efficiency, neutrality, and agency. Proposals should be understood not as solutions but as enabling care, adaptation, and reciprocity. Designing for openness allows ecological and social systems to evolve alongside technologies.

Design prototypes should be understood as probes: they do not predict the future, but test, inform, and enable others to collaboratively shape it over diverse scales of time and connected systems. Any codified set of design principles cannot completely eliminate harm or failure. Its strength lies in its humility: by prioritizing process over product, relation over control, it enables more responsive and ethical engagements. Its value lies not in productivity or scalability but in its capacity to promote situated agency, deepen ecological literacy, and reorient design as a planetary practice. Prototyping must also take into consideration that planetary scale design often does not scale from the local experimentation; complexity science and systems theory reflect this, when large-scale aggregates act differently to the sum of their systemic components (Yuan et al. 2024). Local experiments often fail to generalize as systems aggregate and new cross-scale feedbacks emerge (Braithwaite et al. 2018). Rather than assuming that prototypes will smoothly expand, the design process must embed reflexivity when local dynamics fail to generalize, so the system can reconfigure, decentre default assumptions, and reorient modes of design practice. To 'think like a gardener, not a watchmaker' (INCOSE Complex Systems Working Group 2015) is a helpful conceptual directive to guide this perspectival shift.

By using the *ECT Framework*, designers and citizens may reorient their tools toward ecological attunement, contextual adaptation, and ecosystemic coexistence. Authors propose using the toolkit to imagine speculative technologies that are plausible but existential: grounded in ecological realities and suggesting more expansive social contracts. Amid accelerating ecological degradation (Huesemann & Huesemann 2007) and increasing technological ubiquity (Donges et al. 2017), the need to reconfigure our relationship with both is urgent (Fletcher et al. 2024) and inherently interdependent (Krueger et al. 2022). The complexity of contemporary technologies demands more than instrumental thinking: it requires systemic, ecological understanding. For example, *Resting Reef*, a UK-based initiative that uses cremated human or pet ashes as material to construct bio-receptive reef structures. These submerged memorial reefs create habitats and considerably increase marine biodiversity, simultaneously functioning as carbon sinks and coastal resilience infrastructure. *Resting Reef* (Resting Reef, n.d.) distributes infrastructure as ecologically generative, directly embedding the sociotechnological within living ecological systems. This kind of thinking demonstrates how the *ECT Framework* can move from conception to practice, specifying technologies that respond to ecology while simultaneously reconfiguring citizenship as a coextensive relation between social contracts, material infrastructures, and living systems. We summarize these perspectives as: ***Stewardship / Considers End of life >*** *Proposition considers its end of life, its subsequent stewardship.*

What is an Ecological Citizen(s) Technology?

Ecological Citizen(s) Technologies (UKRI n.d.) deviate from the instrumental view of technologies as artefacts or products; they are processes, practices, knowledge systems and infrastructures (Kline 1985) that embed regenerative intent, catalyze autonomy, and afford relational entanglement between human and nonhuman ecologies. Technology, in this understanding, is a mode of existence within interdependent, overlapping systems (Breitschopf et al. 2023). Technology is situated, participatory, and multiscalar, capable of shaping values, ecosystems, identities, and interspecies relations (Gooding et al. 2025). We propose a vision of design that is aware of its location within a complex fabric of ecological dependencies, tensions, and precarious equilibria. From that awareness follows the multiscalar and temporal orientation of this work: design must be assessed for its effects on humans as well as being situated across ecological niches, across variable scales of time and space. For example, anthropogenic noise interference has been shown to mask critical communication signals, disrupt mating or territorial calls, and reduce hatching success *in* bird populations (Sieving et al. 2024), effects that compound over time and across species. Moreover, chronic noise pollution can restructure biological communities, altering species interactions in ways that persist even after the noise is removed (Senzaki et al. 2020). What seems benign at one scale or moment can, when aggregated and extended temporally, fracture ecological homeostasis and reconfigure system dynamics (Falk et al. 2019).

Ecological Citizen(s) Technologies are those that enable non-extractive, post-participatory (Phillips & Ferrarello 2025), and context-sensitive practices. They are not deployed upon systems, rather they are convergent with them, connecting technological agency with ecological resilience and multispecies interdependence. Distributed sensing infrastructures governed by local communities, or regenerative material systems rooted in Indigenous ecological knowledge, demonstrate this conceptual expansion of technological production. In their comprehensive review of environmental monitoring initiatives, Thompson et al. (2020) found that where Indigenous communities hold greater decision-making power, monitoring programmes diverge in objectives, indicators, and management strategies compared to externally driven models, leading to more contextually attuned ecological outcomes. In many examples, Indigenous participants introduced locally salient indicators that had previously been ignored, reshaping the definition and practice of environmental monitoring; local observers recalibrate assumptions about water dynamics, repositioning technology as a mediator of situated water knowledge. In the Yukon River Basin, Indigenous knowledge from Ruby Village has revealed observations often absent from scientific hydrology, that are critically informative when paired with extant scientific knowledge (Wilson et al. 2015). The Ecological Citizen(s) approach to technology understands the relationship between citizenship and technology as a form of activity produced by people and more-than-human actors; *Ecological Citizen(s) Technologies* are always modes of action insofar as citizenship is enacted through their use and production in practice (Voinea 2017).

For example, *Public Lab's* community-driven air quality monitoring networks enable local residents to build, deploy, and interpret low-cost sensors in collaboration with regional groups, integrating data production with local environmental experience and civic regulation (Rey-Mazón et al. 2018). Another project, *Blue Ceramics*, developed through participatory co-design between marine ecologists and local communities, produces morphing ceramic substrates to restore seagrass meadows by integrating ecological knowledge and iterative material experimentation (Arredondo et al. 2022). These instances illustrate how Ecological Citizenship-informed technological praxis can emerge from place-based ecological knowledge, coordinating design systems with situated experience and ecological process rather than external solutionist imposition. These strategies position technology not as a neutral instrument but a medium through which ecological process, civic organization, and design experimentation are understood as intrinsically associated features; their design and implementation enacts Ecological Citizenship, a conjunction of human and ecological domains that constitutes planetary technological praxis. We summarize this oversight narrative as: ***Benefits wider communities/each other >*** *Through its actions others benefit, like planting flowers, pollinators benefit, as do allotment owners.*

Nature and Technology

The orientation of nature and technology as oppositional domains (Horáková 2017; Uggla 2010) is a persistent cultural position. Deconstructing this dichotomy of 'inert' nature contrasted with 'active' technology, authors propose a more entangled view that sees both as co-productive elements of ecological systems and their planetary context (Ahlborg et al. 2019; Chester et al. 2023). Dominant narratives often position nature as a static backdrop and technology as the active force shaping it; an epistemological bias (Etuk & Inwang 2024; Trächtler 2024) that reproduces hierarchies of control and extraction. Authors challenge this dualism by prioritizing agency, proposing instead that both nature and technology are active participants in shaping emergent systems. Within this view, technologies are not neutral tools but active, multi-domain, productive systems in themselves. Authors reject the presumed notion that nature is a passive resource, and technology an active force of production. Instead, authors understand both as interpenetrating and co-determined, operating through mutual adaptation and exchange. In practice, this orients design beyond artefacts toward the reconfiguration of practices and institutions, and it treats success as the degree to which arrangements enable situated autonomy and convivial use (Voinea 2017b) rather than sole dependence on centralized actors. This correlates with systems thinking in design for social innovation (Donges et al. 2017), transitions research on ecological regime shifts (Sardanyés et al. 2024), and convivial tools that maximize user and community autonomy without excluding systemic approaches (Voinea 2017).

These rhetorically persistent oppositions (Luque-Ayala et al. 2024; Vidal et al. 2024) function as epistemological shortcuts that produce design outcomes discordant with the complexity of ecological systems. When technology is presumed to be inherently extractive and nature inherently virtuous, interventions are structured around false binaries rather than systemic understanding. The consequences are evident in both policy and practice: carbon offset schemes reliant on monocultural plantations (Bosselmann et al. 2024) mimic ecological form without ecological function, resulting in fragile, non-resilient systems that degrade biodiversity under the guise of naturalism (Cheong 2025). At the same time, so-called artificial interventions, such as coral reef restorations constructed from repurposed urban materials or waste substrates, often outperform their 'natural' counterparts in terms of biodiversity and resilience. This reveals that the problem is not artificiality per se, but a lack of systems literacy in design thinking. Technologies do not emerge outside of ecological conditions; they are always already present within them. In the domain of policy and governance, relevant scholarship around Social-Ecological-Technological Systems (SETS) conceives of urban or planetary contexts as inherently hybrid assemblages where infrastructures, ecological processes, and social practices are entangled (McPhearson et al. 2022). For designers, this recognition repositions the focus towards material and procedural entanglements that structure everyday life; objects, infrastructures, and behaviours intrinsic to ecological and technological processes. Rather than relying on performative gestures toward 'nature', it calls for practices that situate design within the negotiation between ecological, social and technological systems.

Natural is not enough. Counterproductive modes of anthropocentrism ingrained in well-intended thinking around categorizations of the natural in opposition to artificiality can counterintuitively reiterate notions of otherness that cast the human as radically disconnected from ecological domains. One such critique (Cronon 1996) sees that this culturally embedded opposition "... embodies a dualistic vision in which the human is entirely outside the natural", and as such reproduces instrumentalist conceptions at the core of contemporary attitudes to the ecological. Even in agricultural systems marketed as 'organic,' ecological risk persists. In one study, (Bahlai et al. 2010) found that two organic pesticide formulations caused higher mortality among beneficial insects than two of four tested synthetic alternatives, frustrating the common assumption that 'organic = benign.' This case underscores that what matters is not reductive categorizations but design fluidity: selectivity, persistence, target specificity, and deployment context. By rejecting the moral shorthand of 'natural = good', a discourse for mobile and ecologically entangled modes of technological authorship is enabled, in which design learns from ecological processes without reductively idealizing them, and in which technology is recast as a situated practice embedded within living systems (Giaccardi et al. 2024).

PhotoSynthetica, developed by *ecoLogicStudio*, demonstrates an effective negotiation of this discourse in action. The project recasts building façades as living systems by embedding microalgae bioreactors within ETFE cladding modules. These bioreactors capture carbon dioxide and pollutants from the air, convert them into algal biomass using solar energy, and release oxygen back into the built environment (PhotoSynthetica, n.d.). The operation of the system demonstrates active participation in urban metabolism, leveraging living processes to reduce energy consumption and improve air quality. (Sedighi et al. 2023). *PhotoSynthetica* engages ecological metabolism directly rather than merely mimicking natural appearances, positioning infrastructure as a living eco-technical agent within its environment. We summarize this overview as: ***Intent on Autonomy >*** *The proposition yields autonomy with citizen(s) not solely reliant on governmental powers.*

Existential vs. Instrumental Technologies

Authors' analysis finds support in theories which distinguish between instrumental and existential technologies (Antikythera n.d.): technologies that reconfigure our perceptions, values, and identities contrasted with those which solely engender specific, quantifiable ends. Instrumental technologies afford efficiency and control; existential technologies reconfigure relational structures, collective values, cultural understandings and perceptual frameworks. *Ecological Citizenship Technologies* understand technology in its existential dimension, without rejecting utility and accessibility as guiding principles.

Technology in this understanding is treated not simply as applied science or engineered artefact, but as a way of knowing and shaping the world; multi-domain, distributed epistemological agents. Existential technologies reconfigure perception and subjectivity, making them integral to ecological learning and adaptation. Rather than understanding technology as the production of tools with fixed purposes in singular problem-domains. Using the notion of existential technology as a design provocation, authors advocate for practices that understand technology as always already embedded within its constitutive material networks; technology as intersystemic, ecological, planetary.

This positioning conceives of technologies as relational and distributed, their logic in confluence with more-than-human ecologies. They do not simply accommodate more-than-human life but arise from dialogical processes that include it (Livio et al. 2022; Oktay et al. 2023). Some projects that embody this ethos:

Augmented Nature: This AR prototype enables residents to visualize and design micro-scale greening interventions in underutilized urban spaces, recontextualizing planting as a sensorial technology, reshaping perception, spatial awareness, and communal ecological imagination. By merging immersive design with ecological feedback, the project reconfigures how people see and act within urban ecologies (Royal College of Art, 2025), AR tools in *Augmented Nature* alter how urban nature is perceived.

Beyond the Colony: This multidisciplinary project positions social insect colonies as collaborators to explore emergent ecological logics and enable multispecies creative collaboration. The technology becomes a platform for distributing agency, restructuring the relationship between human and more-than-human systems. Avoiding predefined outcomes, the process examines how communities relate to ecological agency (Royal College of Art 2025), reshaping how we understand more-than-human intelligence.

Community Energy Citizen Science: Under the *CE-CS* project, local fishers' knowledge is constructed into a real-time water quality monitoring framework, embedding communities and ecologies within the design process. This initiative presents data infrastructure not as a centralized system, but as an *ecological commons*, where technology converges with place-based governance, evolving perceptions of environmental care and collective agency (Stockholm Environment Institute n.d.). *CE-CS* facilitates the coproduction of environmental knowledge and governance structures, developing technological infrastructures that grow from ecological relationships. We summarize this overview as: ***Planet/Natural World Benefit(s) >*** *Deep consideration to the surrounding environment*.

It is also true that the expansive reconfiguration that mass-scale sociotechnological interventions induce have the potential to marginalize communities, reinforce inequalities and bolster hegemonies as much as they might simultaneously liberate and deconstruct others. Ecological impacts of existentially transformative technologies have been widely observed and objectively measured. Scaling AI, for example, expands electricity demand and freshwater withdrawals; model training and inference carry measurable carbon and water footprints, and data centres place additional stress on local basins and grids (Li et al. 2023; Zewe 2025). Electronic waste is rising faster than formal recycling capacity, with most devices not recovered or safely processed (Lee et al. 2017; International Telecommunication Union 2024). Upstream, the minerals that underwrite electrified infrastructures intersect with high-risk social and ecological contexts, with documented land disturbance and biodiversity pressures (Owen et al. 2022). Efficiency gains in digital systems are frequently absorbed by rebound dynamics when they lead to increased usage and consumption, so aggregate burdens persist even as individual devices become more efficient (Freitag et al. 2021; Widdicks et al. 2023).

Planetary-scale computational infrastructures may tend towards the consolidation of geopolitical power and magnify inequalities and even as they claim to democratize planetary knowledge (Crawford 2022; Wu et al. 2022). When conventionally established forms of knowledge production are reordered, resultant structural reinforcement can engender epistemic displacement; by reshaping our modes of knowing, such technologies can marginalize alternative or traditional epistemologies. As Hopster (2024) explains, disruptive technologies can create 'conceptual gaps' that marginalize established interpretive frameworks and deepen epistemic exclusion (Noble 2018). For example, in AI language systems there is often techno-linguistic bias: the system privileges certain linguistic and cultural frameworks and is unable to represent concepts from marginalized languages or worldviews. This creates conceptual gaps: speakers of minority or non-dominant languages find that the system cannot translate or express their concepts, marginalizing their epistemic domain (Helm et al. 2023).

Technological interventions that radically reorient perceptual understandings have the potential to contribute to the loss of human agency, submitting decision-making authority to algorithmic logics; as technology transforms collective perception, it cedes human and more-than-human autonomy to digital authorities that interpenetrate global systems attendant to earthly life (Mitelut et al. 2023). In Antikythera's discussion of sociotechnical disruption, Bratton applies the notion of the Copernican trauma to describe the cultural fragmentation initiated in the contemporary emergence of artificial intelligence; technologies which radically transform human self-understanding have the capacity to destabilize as much as they illuminate, and in fact suggest paradigms beyond entrenched techno-utopian and technopessimistic ideological rhetoric (Nørgård & Holflod 2024), often embedded in anthropocentric positions (Bratton 2024); existential sociotechnical transformation necessitates neither broadly utopian nor terminally apocalyptic outcomes (Ng & Lin 2024; Sand 2024).

Biomimicries

The authors' approach to biomimicry again illustrates this contrast (Mathews 2011). Instrumental applications of biomimicry treat nature as a reservoir of solutions; an Ecological Citizen(s) approach to biomimicry understands ecosystems as partners in interdependent co-evolution (Blok 2022; Hayes et al. 2019). Authors understand Ecological Citizenship technologies in the context of biomimicry as ecosystemic (Blanco et al. 2021), embedded (Flora Robotica, n.d.), and generative (Dixit & Stefańska 2022).

The premise that waste does not exist in nature, as articulated by cradle-to-cradle thinking McDonough and Braungart (2009), illustrates the imperative to design for circularity not in mimicry of surface features, but in consonance with the underlying logics of ecological metabolism (Brown et al. 2004). Biomimicry (Fisch 2017), when reduced to the imitation of individual organisms or aesthetic forms, risks perpetuating anthropocentric modes. Biomimicry at the level of systems (Lebdioui 2022), such as nutrient cycling (Balbinot et al. 2024), mutualistic infrastructures and adaptive feedback enable a generative reorientation with the potential to reposition the process of design towards a mode of ecological mutualism, where the role of the designer is not to impose form upon a passive substrate, but to participate in the unfolding of systemic relationships, attuned to patterns of interdependence, temporality, and more-than-human agency.

One illustration of this thinking around mutualistic ecosystemic biomimicry is the *Living Breakwaters* project by SCAPE (SCAPE Studio, n.d.) in Staten Island, New York. Alongside extant research into 'living shoreline' approaches to coastal restoration (Scyphers et al. 2011), the project sees a chain of limestone and ecologically-modeled textured concrete breakwaters seeded with live oysters; over time the reef structures attenuate storm waves, trap sediment, and grow their own habitat, turning coastal defense into a living metabolic process. This inherent bio-receptivity positions autonomy as more-than-human, decentring anthropic goals without the presumption that this requires abandoning human needs; a distributed, fluid and inclusive priority structure emerges in its place. Rather than extracting a set of features from nature, the design integrates surrounding ocean ecology to bolster shoreline resilience, marine biodiversity and positive systemic interdependence yielding an embedded, generative technology that adaptively constructs itself as ecological conditions change.

Multistability as Design Practice

Technological approaches to Ecological Citizenship must consider multistability: the potential for technologies to assume multiple, context-dependent meanings and uses (Whyte 2015). The use-in-context of a technology over time often exhibits fluidities according to evolving material contingencies. The potential mutability of technology 'in the wild' can engender changes in existing orders of socio-technical relations, or restrict and reinforce them (Shanahan et al. 2024); this means monostable solutionist design approaches must adapt to contend with a potentially fluid array of *in-situ* use cases, with sometimes simultaneously emergent and contradictory cross-purposes (O'Neill 2018). Recognizing the multistable potential of technology allows for the development of approaches that cultivate an ethos of responsiveness over determinism as a positional variation in the design and production of technologies.

One example exists in the emerging space of 'community-mapping' (Parker 2006), especially in its use of drone technology: community-based drone usage in West Kalimantan, Indonesia, demonstrates how drones mutate the sociotechnical dynamics of technological deployment and production. Initially introduced as tools for 'counter-mapping' (Ruzol & Dayrit 2023) to help local communities document forest encroachment and claim land rights, drones quickly acquired local meanings. Citizens repurposed them to monitor river pollution, trace seed dispersal zones, and support intercommunity ecological dialogues (Radjawali 2015).

Beyond the planned scope of their deployment, drones reshaped power relations by transferring authority from external NGOs and state actors towards locally situated, community-led data governance. Yet in some instances, drone ownership and flight privileges were consolidated by regional elites, reinforcing local hierarchies and limiting access. This simultaneous expansion of agency and the reinforcement of inequality exemplifies the multistable mechanics of technological distribution: what emerges in-use often diverges from design intent, revealing how context and control mediate their ecological and sociotechnical impacts.

Given the possibility for deployed technological interventions to produce both novel relational ecologies and reified inequalities, it becomes imperative for design frameworks to anticipate and adapt to emergent, contradictory use patterns, anticipating multistability, uneven agency, and transitioning regimes of control.

Kinect: Multistability in Action

Originally released by Microsoft in 2010 as a consumer gaming peripheral, built on *PrimeSense* (Wong, n.d.) depth-sensing technology, *Kinect* was designed to track bodies in living rooms for interactive gaming development; it very quickly deviated from this intended domain. Artists and interaction designers adopted it for interactive environments and embodied perception (Bowen, n.d.; Stinson 2015; Sorci 2018); scientists reoriented it toward environmental sensing and measurement (Pagliari & Pinto 2015) (Azzari et al. 2013). Diverse communities of practice emerged around *Kinect*, and open software interfaces were developed and shared by practitioners themselves to support them (OpenKinect, n.d.).

This history exemplifies the idea of technological multistability as an unfolding in-the-wild process. A single artefact acquires different meanings and practices as it immigrates from living room to lab to riverbank and gallery; its meaning is not exhausted by its structural features, but by the affordances and behaviours it enables. The *Kinect* functions as an Ecological Citizenship technology when it is situated with communities as a low-barrier sensor that supports autonomous action: quick vegetation scans to evidence habitat change, stream-surface measurements to advocate for water custodianship, or locally governed datasets of citizen-sensing campaigns. The accessibility and portability of the *Kinect* accord with participatory environmental monitoring and citizen sensing frameworks that treat sensors as catalysts for situated inquiry, shared learning, and local decision-making (Palermo et al. 2017).

Hyyppä et al., (2017) show that Kinect can capture tree stem diameters with practical accuracy in the field, and propose crowdsourcing forest inventory by landowners using low-cost depth sensors, contributing local measurements to improve national biomass maps. The device inhabits the utility space of gaming peripherals and *Ecological Citizenship* technology simultaneously: not solely an object but a set of affordances for autonomous action. A living-room game sensor became a civic instrument, enabling non-experts to generate situated forest data, calibrate remote sensing, and participate in custodianship without total dependence on central authorities.

The continual evolution of *Kinect* beyond its target domain reinforces the point. What was designed for entertainment persists in art, robotics, and measurement domains as citizens redesigned its purpose in context. Microsoft ultimately folded the off-target uses of *Kinect* back into the product roadmap. After the hacking and creative repurposing wave, it released *Kinect* for Windows with an official SDK and a 'near mode' function for close-range interaction suited to kiosks, clinics, classrooms and labs, explicitly expanding support beyond conventional and intended use-cases. That pivot later matured into *Azure Kinect DK*, a developer kit aimed at computer-vision and enterprise scenarios and closely correlated with the depth sensing used in *HoloLens*, signaling a wholesale move from game peripheral to general-purpose sensing platform shaped by real-world uptake (Bonnington 2012; Microsoft n.d.). This mutualistic approach to iterative design models a potential structure for the reflexive development of technology as a process that anticipates plausible futures with those affected, incorporates situated ecological knowledge, and stays responsive as meanings and uses change in practice.

Multistability can be more effectively addressed not as a design flaw but a condition of practice: technology becomes a set of relational capacities that can either widen agency or, if intentionally restricted as a response to unintended use, retreat to narrow utility. Designing and implementing such devices as Ecological Citizenship technologies means attending to their affordances, their accessibility, and the social arrangements by which communities can use them in context (Bunting 2025). We summarize this overview as: ***Multistability >*** *(multiple, context-dependent meanings) Works across domains, across cultures and across platforms.*

Perverse Incentives and Paradoxical Consequences

This multistable possibility inherent in the design and production of technological objects and systems means that their deployment must be continuously assessed. Even technologies with well-structured goals can have contradictory outcomes. Technologies intended to serve ecological goals may inadvertently reproduce the very structures they seek to disrupt. Infrastructural design initiatives such as green stormwater installations can inadvertently distribute pathogens in groundwater, acting as an accidental conduit for environmental cross-contamination (Taguchi et al. 2020). These paradoxes concur with discourses of technology as pharmakon (Kern 2014), simultaneously remedy and poison, with an awareness of the potential asymmetries in this conception (O'Gorman 2022). This necessitates anticipatory ethics, multistability as a design consideration, and a transition from instrumental tools to technologies considered in their existential dimension. Alternative strategies must acknowledge this ambivalence without defaulting to reactionism or reductive solutionist impositions, through approaches that embed feedback and ethical foresight into the design process.

Much of the potential misalignment in the deterministic expectations of a technological intervention with the complex unfolding of its deployment exists in the unilateral often relationships ingrained in the process and design of technological production. This means that an imperative component of an Ecological Citizenship-centred approach to technology is the inclusion of an encompassing understanding regarding the motivation of diverse populations, systems, lifeforms and relationships as fundamental in the design process.

The *ECT Framework* examines how unintended consequences can be anticipated, mitigated, or re-channeled through principles of ecological co-design and systemic awareness. In engaging this complexity, authors promote *anticipatory ethics*: an approach that embeds ethical reasoning into the iterative design of sociotechnical systems without expecting perfect foresight, remaining aware of the potential for restrictive, prescriptive or paternalistic solutions that can inadvertently attend future thinking (Nordmann 2014). Structured approaches to this understanding exist as concepts and practices like *mutual shaping* (Winkle et al. 2019) and *ethical foresight analysis* (Floridi & Strait 2020). Codes of practice (Wisconsin Society for Ornithology, n.d.) which position responsibility in relation to ecological systems rather than solely serving human interests can embed ethical post-deployment reflexivity as a fundamental value. More progress towards the amelioration of these potentially problematic effects have been initiated as collective ecological intelligence in the context of Ecological Citizenship through *Participatory Scenario Planning* (Boyd et al. 2015; Galang et al. 2025; López-Rodríguez et al. 2023).

These foresight techniques enable design spaces where collective values, material futures, and ecological consequences are interrogated and rehearsed, instead of being prescribed and determined, allowing designers and communities to encounter complexity with situated speculation rather than expert judgement. Ecological Citizenship research demonstrates how in-situ co-design exercises, rooted in participatory governance and emergent from community knowledge, serve as ethical foresight tools, redistributing authority from technical specialists toward shared ecological agency (Gooding et al. 2025).

While the *ECT Framework* positions anticipatory ethics and systemic foresight as necessary correctives to unilateral technological imposition, it is essential to not to attribute them oracular powers. A genuinely Ecological Citizenship–centred approach must include motivations, interrelations, and lifeworlds across populations, systems, and more-than-human domains from its inception. The *ECT Framework* addresses this by anticipating, mitigating, or rerouting unintended consequences through ecological co-design and systemic awareness. But foresight tools are not neutral (Jørgensen et al. 2008). Umbrello et al., (2023) critiques conventional anticipatory ethics for overconfident assumptions about legibility and control, arguing that futures are always partial, selective, and socially shaped. Meanwhile, Foster's *Future Mundane* (2013) stance warns against designing only for extremes or fantasy, prioritizing futures rooted in ordinary life, resisting compression into grand narratives and triumphalist heroic models.

To counterbalance the shortfalls of rigid foresight tools, the ECT approach should embed reflexive feedback loops, plural forms of projection, and ethical readiness calibration. For example, de Jong (2025) proposes *Ethics Readiness Levels* that map how and when different ethical framings (outcome-oriented vs meaning-oriented) are appropriate, given technological maturity and uncertainty. Likewise, *Infrastructural Speculation* suggests methods that emphasize long-term relations, decay, and emergent use (Wong et al. 2020).

We propose a shift from designing *for* futures to designing *within* emergent processes, enabling communities and designers to monitor, reassess, and reorient together in situ. By prioritizing epistemic humility, adaptive ethics, and the mundane into the ECT position, we preserve its normative force while resisting technocratic determinism and overspecialized prediction. We summarize this overview as: ***Ethical Foresight >*** *ethically looks to the future and considers balanced perspectives.*

Polycentric Arrangements

The presumption of mutual exclusivity between bottom-up communal action and top-down systems of control obscures the potential for effective implementation of environmental initiatives in their hybrid configuration. Evidence from environmental monitoring shows that approaches connecting community knowledge, local priorities, and institutional capacities as a compound system yield robust outcomes, coupling participatory sensing and locally reciprocal ecological practices with state or agency infrastructure. Hybrid networks increase data quality, legitimacy, and persistence over time, simultaneously prioritizing situated knowledge and experience (Eicken et al. 2021).

Bottom-up processes promote contextual legitimacy and care in place; top-down organization cultivates enabling conditions: open data standards, long-term funding, policy protection of commons, cross-scale coordination and longitudinal monitoring. Co-production methods like anticipatory ethics reveal hazards and compromises early in the process, whilst multistability-conscious prototyping prevents over-specification and promotes open-use, guided by end-of-life planning from inception. This form of hybrid approach promotes autonomous, communal practice in accord with ecological and institutional outcomes.

This hybrid logic is also evident in the *Citizens Air Complaint Programme* (New York City Department of Environmental Protection, n.d.), through which community reporting of idling vehicles is integrated into municipal enforcement infrastructures. Local observation and civic participation amplify regulatory reach, while institutional frameworks provide the authority and continuity necessary for enforcement. The result is a hybrid system in which situated knowledge and community action are directly coupled with administrative capacity, reinforcing the broader case for distributed, polycentric environmental governance.
Polycentric governance (Carlisle & Gruby 2017) offers an architecture for such hybrids. As an alternative to a solitary command node or an atomized field of local domains, polycentric orders distribute administration and governance across multiple centres which coordinate, learn, and adapt across scales and systems. This configuration can correlate ecological processes between institutional and local decision venues (Steen 2020), distribute error-correction mechanisms and promote local autonomy through constructive regulation. Moves from monocentric administration structures to polycentric arrangements have been seen to improve cross-scale and adaptive capacity when roles, resources, and accountability are explicitly defined (Chazdon et al. 2020; Ostrom 2010; Wiegant et al. 2022).

For design practice, this means treating Ecological Citizenship technologies not as isolated artefacts but as distributed implementations situated in a polycentric field: created in collaboration with others, non-extractive in operation, intent on catalyzing autonomy, yet interoperable with civic and regulatory systems that secure continuity, equitable implementation and mutual safety. Hybrid forms of organization can improve distributional and procedural outcomes when civic standards, scientific expertise and administrated finance are paired with local ecological custodianship and local knowledge. Systematic reviews indicate that hybrid governance modes support ecosystem services and detriments according to contextual necessity, reinforcing the case for situationally adaptive planning of governance structures which are mutualistic from the outset (Asl & Pearsall 2022; Toxopeus et al. 2020).

Conclusions and Futures

Rather than closing possibilities through prescriptive models, future research must remain adaptive, contingent, and critically productive. Authors call for speculative propositions that extend the principles outlined; non-extractive, designed with-not-for, catalytic of autonomy, contextually appropriate, and systemically entangled, toward uncharted epistemological and ethical terrain. Those prior principles are the bare minimum required to navigate this knotty and interconnected terrain. Authors propose a research orientation that remains critically aware of technology's risks, simultaneously resisting binary oppositions of nature and technology through speculative, regenerative, and participatory design. Authors must contend with what cannot be known in advance: the subjective, affective, and relational dimensions of technology that resist quantification. Ethical unknowns demand reflexivity. How do we design without presuming who or what counts as a beneficiary? How do we stay accountable to more-than human worlds? Research, then, becomes a form of adaptive choreography; an open-ended process of learning with ecologies, rather than prescribing them from outside.

When we neglect to see technology as entangled with ecological systems we risk overlooking cascade effects: small interventions that, when aggregated or extended across time, may precipitate regime shifts or destabilize system dynamics (Rocha et al. 2018). A design choice that seems benign locally or temporally might, when scaled or prolonged, fracture ecological homeostasis. In neglecting technological praxis as essential to Ecological Citizenship, we become vulnerable to invisible harms, relational ruptures, and the erasure of more-than-human constituencies. Within our expanded consideration of Appropriate Technologies, these failures are potentially fatal: a technology that is not constitutive of ecological reciprocity becomes an externality, a reductivity that escapes accountability. As such, the horizon of future research must work toward appropriateness *at* scale and appropriateness *across* scales. Technologies will increasingly operate within systems they cannot fully model. This necessitates flexibility, iteration, and embeddedness. Our framework encourages engagement with the unknown; not as a deficit to be eliminated but as a condition to be designed with. Future work must embrace contingency as a design principle. This framework (see Figure 1) has been built on the typologies and examples within our Network+ funding project and offers a steer to their conceptual repetition. Authors are aware that delivering the 'holy grail' of all elements is exceptionally challenging and if there can be a strategic direction toward *Ecological Citizen(s) Technologies*, it will be a better path to travel. These 'way points' speak broadly to audiences at a high level so they can be appropriated, as the main conclusion has been identifying modalities of repetition, learning and steps to a more ecologically enabled world.

Ecological Citizen(s) Technology Framework

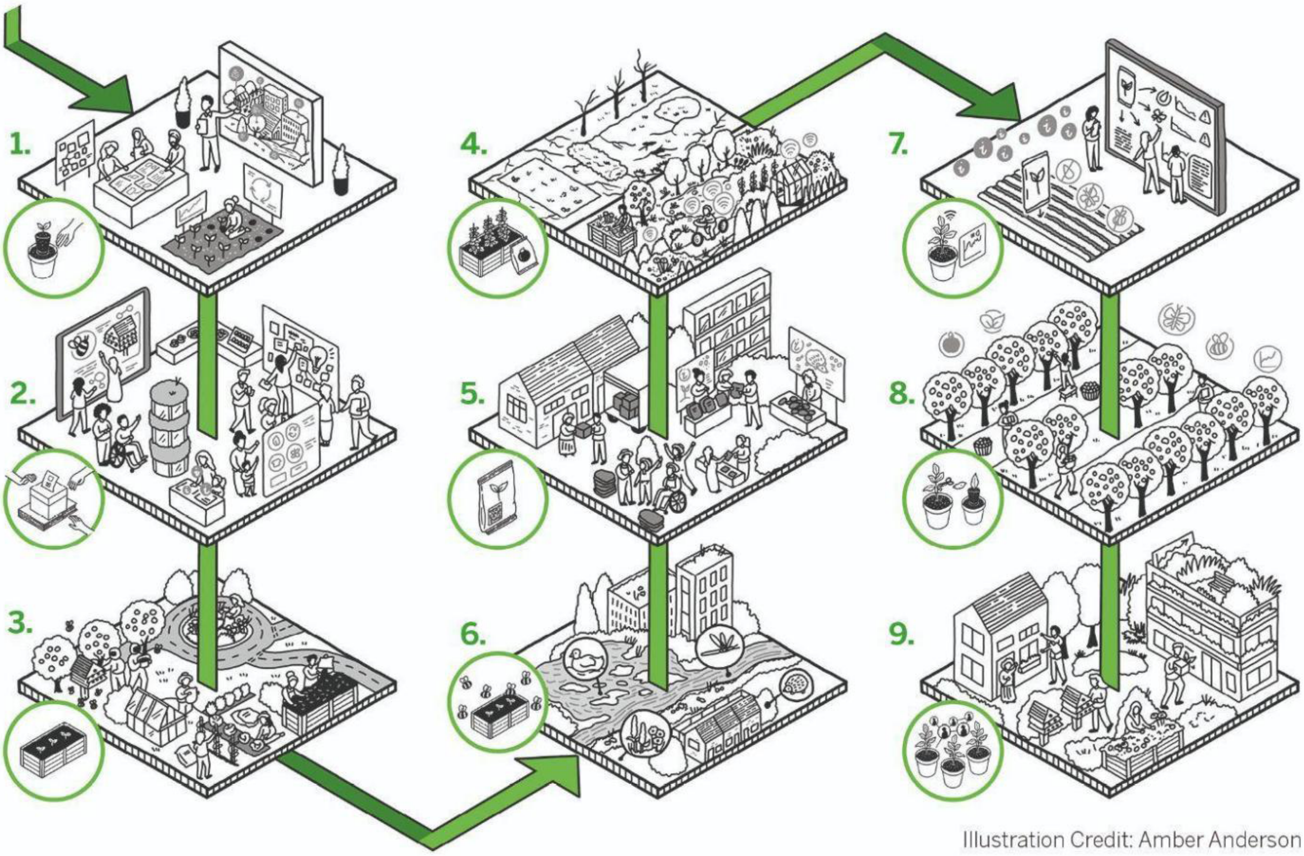

Illustration Credit: Amber Anderson

1. Sustainable Intentions

The proposal initiation and intent is to build sustainable practices.

2. Designed 'with, not for'

Designed with people, openly in collaboration, not inflicted upon them.

3. Benefits wider communities/each other

Through its actions others benefit, like planting flowers, pollinators benefit, as do allotment owners.

4. Planet/Natural World Benefit(s)

Deep consideration to the surrounding environment.

5. Accessible

Easy entry point(s), low friction interventions, could be inter-generational, considering its life over time.

6. Multistability

(multiple, context-dependent meanings) Works across domains.

7. Ethical Foresight

Ethically looks to the future and considers balanced perspectives.

8. Stewardship / Considers End of life

Proposition considers its end of life, its subsequent stewardship.

9. Intent on Autonomy

The proposition yields autonomy with Citizen(s) not reliant on governmental powers.

Ecological Citizen(s) Network+, EPSRC award (EP/W020610/1).

Figure 1: The Ecological Citizenship Technologies Framework, compiled from literature and practice-based projects.

Acknowledgements

Rights Retention Statement: This work was funded by a UKRI grant (EP/W020610/1). For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) licence to any Author Accepted Manuscript version arising. The authors would like to thank: Amber Anderson (amberanderson.co.uk) for their skill in communicating complexity, illustration and narrative and Dan Price for administration and proofing support. The Ecological Citizen(s) is a cross-RCA research network led by Dr. Rob Phillips, with Professor Sharon Baurley, and Tom Simmonds, in partnership with Professor Sarah West of the Stockholm Environment Institute (SEI) at the University of York, and Professor Alec Shepley of the Faculty of Arts, Science and Technology at Wrexham Glyndŵr University, and partners from industry, third sector, NGO. Ecological Citizen(s) is a Digital Economy Network+ project funded by the UKRI Digital Economy Programme, that is focused on digital interventions that would create 'the conditions to make change' towards a sustainable post-industrial society. The work was supported by the EPSRC Network+ award (EP/W020610/1).

References

Ahlborg, H., I. Ruiz-Mercado, S. Molander, and O. Masera. 2019. "Bringing Technology Into Social-Ecological Systems Research – Motivations for a Socio-Technical-Ecological Systems Approach." *Sustainability* 11 (7): 2009. https://doi.org/10.3390/su11072009.

Akama, Y., A. Light, and T. Kamihira. 2020. "Expanding Participation to Design with More-Than-Human Concerns." *PDC: Participatory Design*, June, 1–11. https://doi.org/10.1145/3385010.3385016.

Alves, F., D. Vidal, G. Allegretti, E. Gallo, H. Albuquerque de Castro, and H. Freitas. 2024. "Nature at the Heart of Ecological Transition: Five Ideas to Allow a Plural, Reflexive, Intercultural, Transnational, Ecological, and Dynamic Citizenship." *Social Sciences* 13 (12): 697. https://doi.org/10.3390/socsci13120697.

Antikythera. n.d. *Existential technologies*. Accessed October 9, 2025. https://existentialtech.antikythera.org/rg/.

Arredondo, R., O. Dar, K. Chiang, A. Blonder, and L. Yao. 2022. "Blue Ceramics: Co-designing Morphing Ceramics for Seagrass Meadow Restoration." arXiv.org, January 28, 2022. https://arxiv.org/abs/2201.12200.

Asl, S., and H. Pearsall. 2022. "How Do Different Modes of Governance Support Ecosystem Services/Disservices in Small-Scale Urban Green Infrastructure? A Systematic Review." *Land* 11 (8): 1247. https://doi.org/10.3390/land11081247.

Azzari, G., M. Goulden, and R. Rusu. 2013. "Rapid Characterization of Vegetation Structure With a Microsoft Kinect Sensor." *Sensors* 13 (2): 2384–98. https://doi.org/10.3390/s130202384.

Bahlai, C., Y. Xue, C. McCreary, A. Schaafsma, and R. Hallett. 2010. "Choosing Organic Pesticides Over Synthetic Pesticides May Not Effectively Mitigate Environmental Risk in Soybeans." *PLoS ONE* 5 (6): e11250. https://doi.org/10.1371/journal.pone.0011250.

Balbinot, L., R. Marques, K. Tonello, P. Berguetti, and J. Larsen. 2024. "Recent Insights in Soil Nutrient Cycling: Perspectives From Pinus and Eucalyptus Forest Studies Around the World." *iForest - Biogeosciences and Forestry* 17 (6): 394–404. https://doi.org/10.3832/ifor4530-017.

Bauer, J., and P. Herder. 2009. "Designing Socio-Technical Systems." In *Elsevier eBooks*, 601–30. https://doi.org/10.1016/b978-0-444-51667-1.50026-4.

Bishop, C. 2021. "Sustainability Lessons From Appropriate Technology." *Current Opinion in Environmental Sustainability* 49 (March): 50–56. https://doi.org/10.1016/j.cosust.2021.02.011.

Blanco, E., M. Zari, K. Raskin, and P. Clergeau. 2021. "Urban Ecosystem-Level Biomimicry and Regenerative Design: Linking Ecosystem Functioning and Urban Built Environments." *Sustainability* 13 (1): 404. https://doi.org/10.3390/su13010404.

Blok, V. 2022. "Technology as Mimesis: Biomimicry as Regenerative Sustainable Design, Engineering, and Technology." *Techné: Research in Philosophy and Technology* 26 (3): 426–46. https://doi.org/10.5840/techne2023111166.

Bonnington, C. 2012. "Kinect for Windows: How Gaming Tech Is Migrating to Business." *WIRED*, February 1, 2012. https://www.wired.com/2012/02/microsoft-kinect-for-windows.

Bosselmann, K., K. Gwiazdon, and V. Zambrano. 2024. *Ecological Integrity and International Law*. Routledge eBooks. https://doi.org/10.4324/9781003440871.

Boyd, E., B. Nykvist, S. Borgström, and I. Stacewicz. 2015. "Anticipatory Governance for Social-ecological Resilience." *AMBIO* 44 (S1): 149–61. https://doi.org/10.1007/s13280-014-0604-x.

Bowen, D. n.d. *Underwater*. Accessed October 7, 2025. https://www.dwbowen.com/underwater.

Braithwaite, J., K. Churruca, J. Long, L. Ellis, and J. Herkes. 2018. "When Complexity Science Meets Implementation Science: A Theoretical and Empirical Analysis of Systems Change." *BMC Medicine* 16 (1). https://doi.org/10.1186/s12916-018-1057-z.

Bratton, B. 2024. "The Five Stages of AI Grief." *NOEMA*, July 1, 2024. https://www.noemamag.com/the-five-stages-of-ai-grief/.

Breitschopf, B., A. Grimm, A. Billerbeck, S. Wydra, and J. Köhler. 2023. "Towards Understanding Interactions Between Socio-technical Systems in Sustainability Transitions." *Energy Research & Social Science* 106 (November): 103323. https://doi.org/10.1016/j.erss.2023.103323.

Brown, J., J. Gillooly, A. Allen, V. Savage, and G. West. 2004. "Toward a Metabolic Theory of Ecology." *Ecology* 85 (7): 1771–89. https://doi.org/10.1890/03-9000.

Brown, T., and J. Wyatt. n.d. "Design Thinking for Social Innovation (SSIR)." Accessed October 8, 2025. https://ssir.org/articles/entry/design_thinking_for_social_innovation.

Bunting, G. 2025. "Ghost Hunting, Pornography and Interactive Art: The Weird Afterlife of Xbox Kinect." *The Guardian*, March 6, 2025. https://www.theguardian.com/games/2025/mar/03/ghost-hunting-pornography-and-interactive-art-the-weird-afterlife-of-xbox-kinect

Cai, Y., and J. Liu. 2019. "Designing for Circularity: A Review of Circular Design Approaches." *Sustainability* 11 (15): 4086. https://doi.org/10.3390/su11154086.

Campbell, L., M. Knox, and P. Silverman. 2022. "Regenerative Design Thinking for Urban Resilience." *Journal of Urban Design* 27 (4): 457–74. https://doi.org/10.1080/13574809.2022.2048293.

Capra, F., and U. Mattei. 2015. *The Ecology of Law: Toward a Legal System in Tune with Nature and Community.* Oakland: Berrett-Koehler Publishers.

Ceschin, F., and R. Gaziulusoy. 2016. "Evolution of Design for Sustainability: From Product Design to Design for System Innovations and Transitions." *Design Studies* 47: 118–63. https://doi.org/10.1016/j.destud.2016.09.002.

Cheng, H., and W. Zhang. 2020. "Sustainable Urban Mining: Resource Recovery from Urban Waste." *Resources, Conservation and Recycling* 161: 104945. https://doi.org/10.1016/j.resconrec.2020.104945.

Chiang, K., R. Arredondo, O. Dar, A. Blonder, and L. Yao. 2022. "Blue Ceramics: Co-designing Morphing Ceramics for Seagrass Meadow Restoration." arXiv.org, January 28, 2022. https://arxiv.org/abs/2201.12200.

Clark, W., and R. Dickson. 2003. "Sustainability Science: The Emerging Research Program." *Proceedings of the National Academy of Sciences* 100 (14): 8059–61. https://doi.org/10.1073/pnas.1231333100.

Cloutier, S., J. Knudson, M. Hanisch, M. Margueron, and R. Laurencin. 2021. "Biodesign as a Tool for Resilient and Sustainable Cities." *Frontiers in Sustainable Cities* 3: 636841. https://doi.org/10.3389/frsc.2021.636841.

Coates, J., and R. Ball. 2016. *Bionics in Architecture: Design Inspired by Nature*. London: Routledge.

Connelly, S., and R. Richardson. 2019. "Speculative Design in Regenerative Futures." *Design Studies* 65: 125–48. https://doi.org/10.1016/j.destud.2019.04.003.

Crane, T., and M. Mataric. 2021. "Biomimicry in Urban Infrastructure: Learning From Natural Systems." *Sustainable Cities and Society* 68: 102786. https://doi.org/10.1016/j.scs.2021.102786.

Cripps, E., P. Hunt, and L. Green. 2018. "Circular Economy and Waste Minimization in Design Innovation." *Journal of Cleaner Production* 193: 402–14. https://doi.org/10.1016/j.jclepro.2018.05.178.

Cummings, S., and J. McDonald. 2020. "Regenerative Innovation in the Creative Industries." *International Journal of Design* 14 (2): 45–59. https://doi.org/10.1080/ijdesign.2020.14.2.45.

Curtis, T., and F. Meagher. 2017. "Value-Led Design: Principles for Equity and Social Justice in Design Practice." *Design Issues* 33 (4): 3–16. https://doi.org/10.1162/DESI_a_00466.

D'Amato, D., and R. Korhonen. 2020. "Circular Economy and the Ecosystem Services Approach." *Sustainability Science* 15 (5): 1433–46. https://doi.org/10.1007/s11625-020-00835-w.

Deng, L., and S. Xu. 2021. "Regenerative Design in Biofabrication and Biodesign." *Journal of Cleaner Production* 312: 127632. https://doi.org/10.1016/j.jclepro.2021.127632.

Dixon, K., and M. Patel. 2019. "Speculative Futures in Regenerative Design." *Futures* 109: 102–14. https://doi.org/10.1016/j.futures.2019.03.001.

Doblin, R., and T. Liedtka. 2018. *Design for Growth and Innovation: A Design Thinking Tool Kit for Managers*. New York: Columbia University Press.

Dong, Y., and J. Zhang. 2020. "Bamboo Value Chain: Sustainable Materials for Urban Regeneration." *Resources, Conservation and Recycling* 159: 104810. https://doi.org/10.1016/j.resconrec.2020.104810.

Dorst, K. 2015. *Frame Innovation: Create New Thinking by Design*. Cambridge, MA: MIT Press.

Eames, C., and R. Eames. 1970. *The Eames Design Manual*. New York: Universe Publishing.

Elkington, J. 1997. *Cannibals with Forks: The Triple Bottom Line of 21st Century Business*. Oxford: Capstone.

Fletcher, K., and L. Tham. 2019. *Fashion and Sustainability: Design for Change*. 2nd ed. London: Laurence King Publishing.

Frosch, R., and N. Gallopoulos. 1989. "Strategies for Manufacturing." *Scientific American* 261 (3): 144–52. https://doi.org/10.1038/scientificamerican0989-144.

Gaziulusoy, A. I., and F. Ceschin. 2018. "Sustainability-Oriented Design: Applications in Circular and Regenerative Innovation." *Sustainability* 10 (3): 597. https://doi.org/10.3390/su10030597.

Gleick, P. H. 1993. *Water in Crisis: A Guide to the World's Fresh Water Resources*. New York: Oxford University Press.

Golembiewski, R., and J. Clark. 2017. "Regenerative Urbanism: Integrating Ecology, Economy, and Society." *Journal of Urban Planning and Development* 143 (3): 04017009. https://doi.org/10.1061/(ASCE)UP.1943-5444.0000380.

Gupta, M., S. Kumar, and P. Sharma. 2021. "Tripartite Symbiotic Paradigm for Sustainable Cities." *Sustainable Cities and Society* 72: 103048. https://doi.org/10.1016/j.scs.2021.103048.

Hansen, M., and L. Wrigley. 2016. "Biomimicry as a Tool for Design Innovation." *Journal of Cleaner Production* 135: 1534–45. https://doi.org/10.1016/j.jclepro.2016.06.096.

Harris, F., and T. Garcia. 2020. "Resilient Cities: Planning for Environmental and Social Equity." *Urban Studies* 57 (9): 1821–40. https://doi.org/10.1177/0042098020905511.

Hassan, S., and M. Omar. 2019. "Co-Design and Citizen Engagement in Urban Regeneration." *Cities* 91: 192–202. https://doi.org/10.1016/j.cities.2019.03.015.

Heskett, J. 2005. *Design: A Very Short Introduction*. Oxford: Oxford University Press.

Hill, J., and L. Peters. 2022. "Value Chain Design and Equity in Regenerative Economies." *Sustainable Production and Consumption* 30: 282–93. https://doi.org/10.1016/j.spc.2022.01.009.

Hodgson, A., and K. Baker. 2018. *Biofabrication in Architecture: Materials, Methods, and Design*. London: Routledge.

Hossain, A., and S. Ahmed. 2020. "Informal Economies and Creative Industries: Toward Equitable Urban Innovation." *Urban Studies* 57 (12): 2445–61. https://doi.org/10.1177/0042098020909635.

Jiang, W., and X. Li. 2015. "Research on the Environmental Landscape Renovation Design of Coal Mining Areas Based on Ecological Care Awareness: A Case Study of the Fourth Mine in Pingdingshan, Henan Province." *Design* 17: 102–08.

Johansson, F. 2004. *The Medici Effect: What Elephants and Epidemics Can Teach Us About Innovation*. Boston: Harvard Business School Press.

Kawasaki, G. 2021. "Regenerative Design in Art and Design Education." *International Journal of Art & Design Education* 40 (2): 367–78. https://doi.org/10.1111/jade.12234.

Kim, H., and Y. Cho. 2019. "Bionics and Biomimicry for Sustainable Urban Planning." *Journal of Cleaner Production* 220: 889–99. https://doi.org/10.1016/j.jclepro.2019.02.125.

Koskinen, I., T. Zimmerman, J. Binder, J. Redström, and S. Wensveen. 2011. *Design Research Through Practice: From the Lab, Field, and Showroom*. Waltham, MA: Morgan Kaufmann.

Latour, B. 2005. *Reassembling the Social: An Introduction to Actor-Network-Theory*. Oxford: Oxford University Press.

Lehmann, S. 2010. *Green Urbanism: Learning from European Cities*. London: Routledge.

Liedtka, J., and T. Ogilvie. 2011. *Designing for Growth: A Design Thinking Tool Kit for Managers*. New York: Columbia Business School Publishing.

Manzini, E. 2015. *Design, When Everybody Designs: An Introduction to Design for Social Innovation*. Cambridge, MA: MIT Press.

McDonough, W., and M. Braungart. 2002. *Cradle to Cradle: Remaking the Way We Make Things*. New York: North Point Press.

Miller, R., and J. Hobbs. 2017. "Regenerative Innovation and Imagination: Value-Led Design Approaches." *Journal of Design History* 30 (4): 323–38. https://doi.org/10.1093/jdh/epx015.

Murray, R., J. Caulier-Grice, and G. Mulgan. 2010. *The Open Book of Social Innovation*. London: NESTA.

Papanek, V. 1985. *Design for the Real World: Human Ecology and Social Change*. 2nd ed. Chicago: Academy Chicago.

Parsons, R., and S. Hamer. 2018. “Regenerative Economies and Systems Design.” *Ecological Economics* 147: 1–11. https://doi.org/10.1016/j.ecolecon.2018.01.017.

Pingdingshan Municipal Government. 2014. “Urban Regeneration and Coal Mine Rehabilitation Plan: Pingdingshan Case Study.” Pingdingshan: Municipal Planning Office.

Postrel, V. 2003. *The Substance of Style: How the Rise of Aesthetic Value Is Remaking Commerce, Culture, and Consciousness*. New York: HarperCollins.

Raworth, K. 2017. *Doughnut Economics: Seven Ways to Think Like a 21st-Century Economist.* White River Junction, VT: Chelsea Green Publishing.

Rittel, H., and M. Webber. 1973. “Dilemmas in a General Theory of Planning.” *Policy Sciences* 4 (2): 155–69. https://doi.org/10.1007/BF01405730.

Sanders, E., and P. Stappers. 2012. “Convivial Toolbox: Generative Research for the Front End of Design.” Amsterdam: BIS Publishers.

Schumpeter, J. 1942. *Capitalism, Socialism and Democracy*. New York: Harper & Brothers.

Sennett, R. 2008. *The Craftsman*. New Haven: Yale University Press.

Simon, H. 1969. *The Sciences of the Artificial*. Cambridge, MA: MIT \ Press.

Stiglitz, J., A. Sen, and J. Fitoussi. 2009. *Report by the Commission on the Measurement of Economic Performance and Social Progress*. Paris: Commission on the Measurement of Economic Performance and Social Progress.

Thompson, N., and R. Garcia. 2016. “Speculative Design and the Future of Sustainable Materials.” *Design Issues* 32 (3): 72–86. https://doi.org/10.1162/DESI_a_00388.

Tidd, J., and J. Bessant. 2013. *Managing Innovation: Integrating Technological, Market and Organizational Change*. 5th ed. Chichester: Wiley.

van der Ryn, S., and S. Cowan. 1996. *Ecological Design*. Washington, DC: Island Press.

Walker, B., and D. Salt. 2006. *Resilience Thinking: Sustaining Ecosystems and People in a Changing World*. Washington, DC: Island Press.

Wigley, M. 2011. *White Walls, Designer Dresses: The Fashioning of Modern Architecture*. Cambridge, MA: MIT Press.

Yin, R. 2017. *Case Study Research and Applications: Design and Methods*. 6th ed. Thousand Oaks, CA: Sage.

Yang, J. 2015. “Research on the Environmental Landscape Renovation Design of Coal Mining Areas Based on Ecological Care Awareness: A Case Study of the Fourth Mine in Pingdingshan, Henan Province.” *Design* 17: 1–10.

Zhang, L., and Y. Wang. 2021. “Growing Materials: Biofabrication for Sustainable Design Innovation.” *Journal of Cleaner Production* 288: 125635. https://doi.org/10.1016/j.jclepro.2020.125635.