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Naturalizing Technology, Technologizing Nature: On the Global Political Ecology of Smart Environments

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Abstract
We critically examine how integrating sensor-based technologies into urban green infrastructures—exemplified by smart trees in Augsburg (Germany) equipped with soil moisture sensors—both reshapes and re-politicizes the relationship between humans, nature, and data. Terms such as The Internet of Nature or the Wood Wide Web naturalize the data-driven management practices of smart forestry and frame them as neutral means for environmental protection. However, this overlooks the ways in which data is produced, interpreted, and embedded in specific socio-technical configurations that are anything but neutral. Drawing from political ecology, science and technology studies, and Niklas Luhmann's concept of functional simplification, we argue that well-known critiques of instrumentalizing nature do not sufficiently grasp what is happening when we increasingly come to rely on digital technologies to secure ecosystem services. Instead, we plead for understanding these developments as a technologization of nature. As environmental conditions become increasingly unstable due to climate change, reliable ecosystem functioning must be artificially maintained. In practice, this means isolating and optimizing selected causal relationships—such as a tree's water intake—to ensure reliable performance. This approach transforms once self-sustaining ecological processes into engineered systems, masked in the rhetoric of natural networks. Moreover, the global political economy that enables these smart interventions disproportionately favors the wealthy regions of the Global North, whose technological infrastructures depend on unequal resource extraction and labor conditions elsewhere. Thus, while datafication and sensor technologies may enhance certain aspects of urban resilience, they do so in ways that reinforce inequalities. At the same time, their naturalization obscures the complex, socially contested arrangements that underpin these newly technologized ecosystems.

Keywords smart climate trees, smart environment, science and technology studies, political ecology

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1. Introduction

Green infrastructures, particularly urban trees, have become central to urban adaptation strategies against rising temperatures. However, young and newly planted trees face heightened vulnerability to climate stressors. Therefore, cities are increasingly turning to sensor technology to monitor and manage optimal tree growth, paving the way for smart green infrastructures. Digital technologies have become irreplaceable for monitoring and better managing ecosystem services in the city and highlight a data-driven approach to urban resilience (Galle et al., 2019).

Data-driven decisions are often viewed as neutral and objective, especially when framed in a naturalizing language. However, terms such as the *Internet of Nature* or the *Wood Wide Web* obscure the fact that the naturalization of technology is accompanied by a technologization of nature. Sensor technology turns trees themselves into a technology by singling out, optimizing, and ensuring that these trees reliably provide their ecosystem services. Efforts to technologize nature are embedded in a highly unequal global political ecology. Smart urban infrastructure is political insofar as it represents an effort to make (urban) ecosystems resilient that is only available to a minority of humanity.

This commentary employs Augsburg's (Germany) tree-planting efforts as a case study to critically examine the intersection of smart technologies and urban green infrastructure. Augsburg's initiative to equip newly planted trees with sensors to monitor and manage their growth provides a concrete example of how digital technologies are being integrated into urban ecological governance. The seeming neutrality of smart sensor technologies in urban governance is paralleled by tendencies to naturalize (and thereby depoliticize) smart technologies through terms such as the Internet of Nature or the Wood Wide Web. Our analysis is grounded in theoretical perspectives from political ecology and science and technology studies, with particular emphasis on Niklas Luhmann's (1998/2021, p. 522) concept of *functional simplification*. This concept highlights how technology consists of isolating and simplifying certain causal relationships so that they repeatedly and reliably perform a certain function. This perspective emphasizes well how urban trees become limited to certain ecosystem services but also how global unequal exchange dynamics between the Global North and South disappear behind the functional form of technology.

2. Smart Environments

Trees in urban spaces have several benefits for people living in the city, such as shade and cooling effects during heat waves (Artmann et al., 2017; Iungman et al., 2023), and other relevant health benefits, like mental health improvements (Wolf et al., 2020). Beyond these benefits, they provide aesthetic value and enhance the appearance of built-up streets. Therefore, many cities aim to plant more trees, for example, Augsburg is planning to plant about 800 trees, funded mostly by the federal government. Officials in Augsburg have estimated that a single young tree may require up to 110 liters of water per week during the summer months, a demand that necessitates careful monitoring and management. In response to these challenges, cities are increasingly adopting sensor technology to monitor and support the growth of young trees, indicating the rise of smart green infrastructure.

The concept of Smart Environments—including Smart Water, Smart Agriculture, and Smart Forests—embodies a data-centric approach to ecosystem management. However, the data is not just present, but it is made available through practice (Nost & Goldstein, 2021). In forests, digital technologies are increasingly used to monitor forest health, track logging, and optimize resource use (Gabrys, 2020; Campbell, 2017). Forests are made smart by installing sensors on tree trunks or in the ground to measure the sap flow or soil moisture (Gabrys, 2020). Additionally, drones are used to monitor forest fires or even to spread seeds (Giuseppi et al., 2021; Buchelt et al., 2024). These digital forest technologies have been dubbed the *Internet of Trees* in reference to the Internet of Things (Gabrys, 2020). The digital monitoring of green infrastructures such as (urban) trees is seen as "the next frontier in ecosystem management" by Galle et al. (2019, p. 279) aiming to "change our relationship with the natural world in the urban age."

Therefore, technological devices such as sensors are utilized to control and enhance the functioning of (urban) ecosystems (Galle et al., 2019). Goldstein and Nost (2022, p. 1) argue that "our relationships with nature are increasingly digitized." This is particularly evident in smart cities, where so-called "smart green infrastructures" are monitored, digitally managed, and augmented (Gabrys, 2022, p. 13). This practice of understanding nature as infrastructure, which can be programmed to respond to environmental changes to achieve sustainable urbanism, puts ecosystem services at the center of attention (Gabrys, 2022). Sensors and the sensor network offer real-time measurement of multiple environmental parameters (e.g., humidity, water levels, leaks, temperature, and other physical properties) with minimal human intervention (Baycheva-Merger et al., 2024). Digital environmental data has a growing importance for decision-makers, as it serves as a basis for decisions to consciously respond and adapt to the environmental changes caused by climate change. Governance, based on environmental data, involves a turn to data as a seemingly neutral and objective base for accountable environmental decision-making, as it makes invisible problems visible and solvable (Nost & Goldstein, 2021). With sensors, "worlds are made sense-able" and "nature is brought online to perform" (Gabrys, 2022, p. 15).

3. Naturalizing Technology

All of this involves a technologization of nature. However, to set aside the political tensions of such a project, some scholars have instead characterized smart environments as a naturalization of technology. For example, Galle et al. (2019) introduce the Internet of Nature, a framework that digitally represents and manages urban ecosystems. It uses technologies such as remote sensing, information and communication technologies, sensors, data loggers, and cloud computing with the aim of enhancing urban nature and achieving self-organization and self-regulation of the urban ecosystem.

Another example concerns Nadine Galle's (2024) latest book *The Nature of Our Cities*. On its cover, it features a tree with roots symbolizing data streams that connect it to the urban fabric. These data streams mirror natural processes such as trees exchanging carbon and nutrients with fungi and other organisms through mycorrhizal networks (Song et al., 2015). Inter-plant communication through mycorrhizal networks is often framed as how trees talk (Frawley, 2021; Galle, 2021; Simard, 2016) or labeled as the Wood Wide Web (Castro-Delgado et al., 2020). With technology, the Internet of Trees (Gabrys, 2020) seemingly extends these biological networks—sensors translate biochemical processes into digital data streams. These technologies appear to act as mediators. They link natural mycorrhizal systems with urban data flows and create the perception of communication between nonhuman life and humans.

However, despite these compelling analogies, the true ecological role of mycorrhizal networks remains unclear. As Figueiredo et al. (2021, p. 9) caution, "the real effect of the common mycorrhizal networks in shaping plant communities is still not clear." Furthermore, trees do not inherently "communicate" with humans; rather, sensors convert biochemical signals into numerical data transmitted via low-frequency radio telemetry. This data is then visualized in formats such as tables, graphs, or maps, creating an illusion of objectivity and neutrality. By presenting real-time information on factors like soil moisture and temperature, these dashboards enable city officials to monitor and optimize urban ecosystem management (Kitchin et al., 2015).

4. The Politics of Smart Environments

In Augsburg, the Department for Green Space Management chose to use soil sensors to measure temperature and soil moisture, prioritizing watering efficiency over more complex sensor capabilities, such as tracking water transport within trees. The choice of sensors highlights the human agency involved in interpreting and valuing data. As Borgmann gen. Brüser et al. (2017) note, advancements in sensor technology, such as transitioning from volumetric water content sensors to those measuring water tension, influence the quality and applicability of the data collected.

The interaction between human and nonhuman actors through sensors raises questions about the neutrality of data. Decisions about which data to prioritize and how to act upon it reflect human values, priorities, and power dynamics. In the context of smart climate trees, this prioritization embodies a clear politicization of nature, where the framing of data and its subsequent use are not neutral but are deeply rooted in socio-economic goals. The focus on optimizing tree growth to maximize ecosystem services aligns with neoliberal logics, emphasizing efficiency, productivity, and utility. These logics dominate the discourse and reflect broader Smart City narratives that treat urban infrastructures and ecosystems as tools to attract investment, drive economic development, and secure human well-being (Kitchin, 2022). This approach reinforces the commodification of nature, in which nonhuman life is managed and governed primarily for human benefit. In this framework, trees are monitored and controlled to grow as quickly and effectively as possible, reducing their ecological complexity to a narrow set of services. This reductionist view serves human-centric objectives, obscures the inherent ecological value of trees, and further embeds them within a system of governance that prioritizes economic and utilitarian outcomes over ecological integrity.

5. Technologizing Nature

However, the problematic developments in smart environments do not merely instrumentalize nature. If we were to leave it at that, we would simply reiterate a criticism that could just as well be applied to basic techniques such as agriculture or the domestication of animals. We argue that smart sensor technologies applied to natural environments capture more specifically a novel trend toward technologizing nature in times when its reliability is threatened by an unreliable climate. Drawing on Niklas Luhmann, we conceptualize technology as a "functional simplification" (Luhmann, 2021, p. 524) through which humans isolate and simplify certain causal relationships so that they can repeatedly and reliably carry out a certain function. This theoretical lens allows us to see how specific functions of nature, previously carried out without human intervention or oversight, are now isolated, ensured, and enhanced. However, given the global political economic inequalities, this will only be a realistic option for a small selection of (largely urban) ecosystems for a minority of humanity.

Technologies in the form of a functional simplification allow us to focus on a very limited set of causal relationships—those relevant for the technological function. We ignore all other causal relationships as long as they do not impede the given function. There is a depoliticizing aspect to this that is at the same time highly political. Once we establish a functional simplification, we do not need to repeatedly discuss it. In this way, technology "saves" communication and consensus (Luhmann, 2021, p. 518; Pieper, 2024, p. 21). If something functions, it functions and becomes proof of its own legitimacy. Of course, this leaves open the question for whom a technology functions. We will come to that later.

With this conceptualization of technology at hand, let us first establish that there is nothing surprising in the fact that nature itself can be turned into a technology. This is what happens to our trees in the smart city. We isolate certain functions of the trees—they provide shade, filter the air, and capture carbon. Then, we identify which variables reliably produce such functions—precise nutrient and water management. Reliability is an important keyword here: If we were to merely plant a tree without sensors, the risk would be much higher that something unforeseen happens—such as a drought—that kills or damages the tree. The tree without sensors would then be—especially in increasingly common extreme weather events—an unreliable technology and therefore hardly a technology at all. We can thus increase the reliability of a tree and turn it into a technology by equipping it with sensor technology.

How does that constitute a functional simplification? Is it not rather the case that something as banal as the planting of a tree is turned into an overengineered technological endeavor? Are we not turning something very simple into something very complicated? That is indeed what's happening. Still, it does not contradict the principle of functional simplification as long as we assume that functionality is closely bound to reliability. And in the increasingly unreliable climate brought about by the unfolding climate catastrophe, it seems that increasing human intervention is necessary so that we can still rely on previously taken-for-granted processes in nature.

This is precisely the point at which the exemplary case of the sensor-equipped tree reveals a trend that goes way beyond the problem of instrumentalizing nature. Nature is not merely increasingly instrumentalized for human needs but must also be increasingly overseen through technological means. Paradoxically, nature becomes technologized so that it can stay natural, in the sense that we can take it for granted. In an unstable climate, so the technocratic hope, sensor technology paired with AI will increasingly be used to ensure that ecosystem services are delivered—because left on its own, nature can no longer be relied upon.

It is illusory to think that a large-scale smart application of technology to ecosystems would indeed be feasible on a global scale. This is because the increasing technologization of nature relies on a global political economy in which technological solutions in affluent states of the Global North are enabled through a net extraction of labor time, energy, land, and resources (in short: biophysical resources) from the Global South (Dorninger et al., 2021). It is widespread to think of technologies primarily as achievements of engineering or as applied science. However, if we look at the actual material processes that underlie modern technology, a different picture emerges: Rather than understanding technology as ingenious achievements for humanity as a whole, we should consider the extent to which technologies represent strategies of some parts of humanity to appropriate the biophysical resources from other parts of humanity (Pieper, 2024).

This is the core problem of technologizing nature: A situation in which ecosystem services can only be reliably ensured through advanced sensor technology and AI is a situation in which a stable natural environment is coupled to one's position in the global political economy. We should not forget this aspect regarding efforts to monitor nature through smart technologies. It is a particular nature for a particular part of humanity that is "brought online to perform" (Gabrys, 2022, p. 15). Here again, the notion of technology as a functional simplification is useful. Not only are physical aspects simplified in the form of technology, societal aspects are simplified as well. Smart technologies in the Global North are affordable not least because of cheap labor and toxic rare earth mining in China. The concrete exploitation of laborers and toxic mining operations disappears behind the simplified functional form of technology, just as the engineering particularities do. The extent to which global inequalities are a precondition for the existence of modern technologies has been especially pronounced in political ecology discussions on ecologically unequal exchange (Hornborg, 2014, Givens et al., 2019, Roos, 2022). However, while the engineering particularities obey unchangeable natural laws, the exploitation of laborers and the destruction of nature follow the social laws of global capitalism that are very much changeable. It is through the fetishization of technology that this simple fact disappears from view (Pieper, 2024, p. 22).

6. Conclusion

The ecological crises of the 21st century are increasingly leading to unstable ecological processes. Stable and functioning ecosystems that society can simply take for granted thus become dependent on additional technologies such as sensors, servers, and computers. The concept of functional simplification highlights that technologies are well equipped to substitute this taken-for-grantedness of nature. Once established, technologies present themselves to us through their functionality, behind which a hidden complexity can be safely ignored and taken for granted—as a second nature (Luhmann, 2021, p. 522–523).

However, this second nature consists not only of unchangeable natural laws but of social arrangements that could just as well be made different. Overcoming the fetish of technology means that we ought to look critically and carefully at the global and local social arrangements that smart-city technology and the datafication of nature demand us to just take for granted.

Planting smart-sensored trees, as in our case in Augsburg, is not a problem per se. What we have tried to highlight in this short article is that the larger trends in which such efforts are embedded are indeed problematic. The high inequalities existing in the global political economy permit only a minority of humanity to ensure the functioning of their environments by rendering it "computable" (Lin, 2022, p. 285). At the same time, the production process of smart technologies exacerbates the shifting of environmental costs to the Global South. Data-driven environmental governance (Nost, 2022) is therefore anything but apolitical, even if naturalized terms such as the Internet of Nature or the Internet of Trees suggest otherwise. Smart technological solutions are embedded in the very processes of ecologically unequal exchange that are at the heart of dynamics and inequalities of the climate crises. They provide resilience for the ecosystems of some but are no viable solution for the larger part of humanity.

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