

# – INFRASTRUCTURAL EXTENSIONS: Rethinking Infrastructure in Urban Studies

SIMON MARVIN, COLIN MCFARLANE AND JONATHAN RUTHERFORD

## Abstract

*This essay explores how contemporary urban infrastructure is being conceptually and operationally extended into new domains. Across five key arenas—elemental, care, more-than-human, cyber-physical and the neurotechnical—we trace how infrastructures are no longer confined to traditional networked systems but instead permeate and co-compose atmospheres, bodies, ecologies and cognition. These extensions reconfigure what infrastructure is and does, operating as agents of socio-technical modulation under conditions of planetary crisis. We argue that these emergent infrastructural forms constitute a significant shift, where the capacity to live, sense, feel and adapt is increasingly subject to infrastructural capture, stratification and control. The essay reflects on the risks of conceptual overreach while asserting that a more expansive understanding of infrastructure is necessary to grasp contemporary urban governance. We conclude by proposing a renewed research agenda for urban infrastructure studies that is interdisciplinary, ethically attuned and responsive to the operationalization of life itself under conditions of turbulence and inequality.*

## Introduction

Infrastructure is no longer merely the hidden substrate of modernity working through the pipes, cables and roads that quietly support urban life. Over the past two decades, infrastructure studies research has redefined infrastructure as, among other things, affective, ecological, cognitive and atmospheric. Infrastructure is now seen as relationally co-constituted and emergent, shaped as much by non-human life, elemental forces and digital systems as by technocratic planning, physical form and built networks.

This intervention essay argues that urban infrastructure studies are undergoing a conceptual threshold moment. Across diverse literatures in media studies, anthropology, sociology, cultural studies and beyond, infrastructures are being extended into domains once seen as beyond urban concern, reaching into the air and atmosphere, care and emotion, microbes and animals, digital cognition and neural feedback. These infrastructural extensions do not simply augment the field but challenge its ontological and political foundations. Earlier critical scholarship in urban studies has moved infrastructure out of the shadows and into plain sight, as plural, contingent and contested. This essay argues that the current shift, often characterized as the ‘infrastructure turn’ across the social sciences, means we must confront infrastructure not just as a system or substrate, but as a modality of modulating life, matter and cognition.<sup>1</sup>

We define infrastructural extensions as emergent formations through which infrastructure comes to operate in new domains, potentially generating new urban landscapes that reorganize urban life under planetary crisis. These extensions mark

We would like to thank the two reviewers for their constructive and critical engagement with the essay. Their insights significantly improved the focus and potential contribution of the work. Any remaining errors are our own.

<sup>1</sup> Given the limits of the Interventions format, this essay does not attempt to offer an exhaustive account of the extensive domain of urban infrastructure scholarship. The essay explicitly reviews current work on infrastructure within the social sciences—but largely outside urban studies—and then seeks to reflect on the urban implications. We hope colleagues will understand the selective nature of the reference list, that cannot totally capture the full range of work that has influenced our thinking.

a shift from managing flows and resources to governing climate, subjectivity, species and sensation. They transform infrastructure into a tool not only for continuity and provision but also for differentiation and speculative optimization. Our contribution is to map five such extensions—elemental, care, more-than-human, cyber-physical and neurotechnical—and to reflect on what they mean for urban infrastructure theory, politics and research practice.

The essay does not aim to redefine urban infrastructure, and we are aware of the risks associated with conceptual overreach. Instead, we argue that paying attention to these extensions is analytically necessary to *diagnose* the infrastructuralization of urban life in its contemporary forms. Rather than flattening the concept of urban infrastructure, these new domains foreground changing and urgent modes of infrastructural power that capture atmosphere, affect and the neural as domains of strategic intervention. These extensions are not uniformly emancipatory or oppressive but are instead terrains of ambivalence and experimentation.

In what follows, we first chart these five extensions and explain why they are important to urban studies; second, we highlight their implications for more reflexive, critical and anticipatory urban infrastructure studies; and third, we conclude by outlining the essay's core contribution and the consequent questions and next steps for urban research.

### **Five extensions of infrastructure: from provision to modulation**

This section identifies five domains in which urban infrastructure is being extended by disciplines within the social sciences but largely outside urban studies. These extensions do not represent a definitive typology, nor do they attempt a comprehensive categorization. Instead, they function as diagnostic devices to trace what we see as key emergent transformations in the form, function and politics of infrastructure. Across these domains, we observe a shift from infrastructure as a system of provision to infrastructure as a mode of modulation. The extensions outlined below are illustrative of this shift and reveal how infrastructure increasingly operates across new registers of the atmospheric, emotional, biological, digital and neural life.

#### – Elemental infrastructures

The first extension moves from classic notions of networked infrastructures, such as water, energy and transport systems, to what might be called elemental infrastructures. This body of work foregrounds the infrastructuralization of elemental matter: air, water, earth, chemicals, temperature and atmospheric media (Engelmann and McCormack, 2021). This work extends and diverges from research on infrastructural metabolism (e.g. Keil, 2020; Gandy, 2021) in new ways, as scholars in geography and science studies investigate how the elemental is not only shaped by infrastructure but *becomes infrastructural in itself*. For example, Adey (2013; 2015) and Engelmann (2015) investigate how air and atmosphere become operationalized through surveillance, security and health regimes, while McCormack (2017) and Brodie (2020) examine how stratospheric winds and cool climates are extracted and mobilized to support data infrastructures, pointing to a new political economy of 'climate extraction'.

These studies demonstrate that infrastructural systems are ever more entangled with the elemental at multiple scales. It is not that infrastructure was previously separated out from the elemental. Consider, for instance, the extensive history of research on metabolic infrastructures, such as water, waste and gas (e.g. Otter, 2008). However, the forms and extent of this are multiplying, as are the research engagements with them. As infrastructures become more attuned to matter, molecule and milieu, the elemental emerges as both a medium and an agent of infrastructural power. For instance, data centres are increasingly sited in cold climates not only for cost efficiency but also as part of a thermal ecology that aligns with planetary temperature differentials

(Velkova, 2016; Childs, 2022). This reconceptualization invites a broader inquiry into how urban climates (Anwar, 2023), subterranean geologies, and even chemical flows within bodies (Balayannis, 2020) become governed as part of extended infrastructural regimes. The urban implications are profound as infrastructures now modulate elemental conditions, including air quality, temperature and humidity, in everyday governance, demanding new attention to atmospheric politics and material agency.

While this shift and the research surrounding it are primarily an effort to accommodate and adapt to climate urbanism, a set of other intersecting logics is also at play. These include a growing and deeply unequal political economy around 'comfort', inequalities in access to and protection from different kinds of air (Graham, 2015; Ghertner, 2021), speculative imperatives to develop new forms of mineral extraction, political efforts to securitize atmosphere for some and to generate surplus, and so on (Clark, 2018; Stamatopoulou-Robbins, 2019). For research on infrastructure, the critical question is how to foreground a socially and environmentally just agenda on the infrastructuralization of the elemental at different spatial scales.

#### – Infrastructures of care

A second extension reconfigures the notion of social infrastructure through a feminist and affective lens, foregrounding infrastructures of care. While classic formulations of social infrastructure focus on the public spaces and institutions that support sociality (Latham and Layton, 2022), newer scholarship emphasizes informal, affective and embodied practices that sustain life amid austerity, state withdrawal and crisis. Drawing on Simone's (2004; 2021) influential notion of 'people as infrastructure', feminist urbanists such as Emma Power, Kathy Mee and Miriam Williams extend infrastructural thinking to encompass the ethics, labours and materialities of care (Power, 2019; Power and Mee, 2019; Power and Williams, 2020). Here, infrastructure is partly about physical provision but also about sustaining relational ecologies, including food sharing, housing support, mutual aid and emotional labour (Strauss and Xu, 2018). In a time of pandemics and deepening variations of austerity and right-wing ascendancy, such logics of care have become and will continue to become increasingly important in the reproduction of the city (Peake and Rieker, 2013; Ali *et al.*, 2023; Peake *et al.*, 2024).

This form of infrastructural extension is evident in urban contexts characterized by precarity, where informal institutions and everyday practices serve as substitutes for failing or otherwise inadequate formal systems. Alam and Houston (2020) conceptualize care as an alternative infrastructure that mediates life at the margins through relational processes of provisioning and improvisation. These infrastructures often emerge in domestic spaces, community gardens, convenience stores (Ujikawa, 2025) or digital platforms, complicating conventional spatial boundaries of infrastructure (Nowak, 2023). Infrastructures of care challenge the technocratic, masculinist, and often depersonalized logics of urban planning. They emphasize a view of the city not just as a space of systems and flows, but as a space of support and vulnerability. The implication is that in studies of infrastructure, it becomes important to pay greater attention to social reproduction in relation to processes of production, maintenance and reconfiguration (Hall, 2020). Urban governance, in turn, must reckon with the political labour of care, recognizing its infrastructural value and the socio-material arrangements that sustain it.

It is tempting to position the growing processes and research concerns connected to care infrastructures in opposition to those forms of elemental infrastructures that would siphon off and control access to certain atmospheric conditions in the city. Our view is that a more expansive reading is necessary. Care, of course, is a fraught politics, at once indispensable and an essential ethic of intervention we might wish to find more creative ways of recognizing and supporting. It is also a social technology strategically used by the right in neoliberal times to bypass state responsibilities to invest in processes that might reduce the need for the considerable labour, often gendered

and racialized labour, of care. The question of care opens, first, a requirement for us to rethink infrastructure and its ethical entanglements, and second, a larger and complex debate on how and where to position care in the contemporary stakes of infrastructural provisioning, the role of the state and political-economic change.

– Multispecies infrastructure

The third extension discloses a set of conceptual and political puzzles in the context of the entanglement of infrastructure with non-human life. Traditionally, infrastructures have been understood as anthropocentric: designed by and for humans. Recent work in urban political ecology and posthuman geography has foregrounded the agency of non-human entities, including animals, plants, fungi and microbes, in co-producing multi-species infrastructural systems (e.g. Barua, 2021; Barua and Sinha 2023). Three modes of infrastructuralization can be identified.

First, repurposing infrastructure, where non-human life adapts and appropriates existing infrastructures in unintended ways. Gandy (2013), Jasper (2020) and Wilson (2022) show how urban ecologies emerge from infrastructural leftovers and cracks, generating new concerns around multispecies coexistence in which non-human life actively reconstitutes the form of infrastructure. Second, recombinant infrastructures emerge when urban environments become sites of spontaneous ecological formation, producing hybrid systems that defy original design intentions. These are infrastructures that develop despite, rather than because of, human planning. One striking example involves the role of microbial life in reshaping infrastructures. Microbes are reconstituting infrastructure in two significant ways: first, as threats, such as in the case of the Covid-19 pandemic (Gandy, 2022) or the spread of diseases like cholera and multidrug-resistant tuberculosis; and second, through processes of microbial optimization, which are increasingly seen as beneficial. These ‘virtuous’ microbial interventions are expanding rapidly, ranging from wastewater epidemiology to mapping the bodily biome (Lorimer, 2020; Arefin and Prouse, 2024). In this view, microbes become active agents in infrastructure, shaping how health, risk and life are governed in urban systems.

Finally, reconciliation involves the construction of new infrastructures that are explicitly designed to accommodate non-human life, including green corridors, wildlife overpasses, botanical gardens or climate-controlled biomes (e.g. Zellmer and Goto, 2022). While such efforts often involve a politics of management and control, they also reflect an emerging ethic of cohabitation.

Concerns with non-human life are not in themselves new in research on infrastructure, but what we are now seeing is a more systematic challenge to the ontological boundaries of infrastructure where the conceptual and ethical implications are to rethink infrastructure as radically distributed and upended by climate change (and here we note the links to ‘care’ discussed earlier). These shifts re-cast the urban itself as a multispecies milieu where infrastructures mediate interspecies relations and ecological survival (Hayles, 2021). The infrastructuralization of the non-human extends to the critical urban tradition of the ‘right to the city’ by reorienting infrastructural politics: whose lives are supported, excluded or sacrificed in the name of operational efficiency, and in a time of intensifying pressure resulting from climate change and neoliberalism? The place of infrastructure as a conceptual, political and operative vehicle will be vital here, as will the question of precisely what kind of ‘vehicle’ infrastructure then is.

– Cybersymbiotic infrastructures

A fourth emergent extension is that of *cybersymbiotic and cyber-physical infrastructures*, which reconfigure urban operational landscapes through increasingly complex and intertwined relations between humans, machines and embedded physical systems (Hayles, 2017; 2021). Drawing on recent work on AI, robotics,

autonomous systems and digital twins, this extension builds upon the rise of intelligent infrastructures that sense, interpret and act upon urban environments in real time (Urry, 2016; Crawford, 2021; Kitchin and Dawkins, 2025).

Cybersymbiosis refers to the integration of machine learning, sensor networks and algorithmic reasoning into the ecologies of urban life, not only as overlays but also as co-evolving systems that adapt to, learn from and reorganize cities. These include ambient sensing, predictive analytics, robotic mobility systems and real-time service orchestration that influence everything from energy use to public health logistics (including forms of care). Meanwhile, cyberphysical infrastructures integrate software intelligence with physical operations, including automated warehouses, smart energy grids and robotic delivery networks, where computation and physical infrastructure are fused into responsive, adaptive systems (e.g. Barns, 2019; Pollio *et al.*, 2023).

What is infrastructuralized here is not just connectivity or computation, but a form of machine-mediated cohabitation that is pushing at transformations in urban metabolisms and decision-making. These systems increasingly participate in resource allocation, risk management, traffic regulation and even interpersonal coordination. As such, they demand a rethinking of infrastructure as a site of algorithmic agency and cybernetic feedback, co-produced by human and nonhuman actors. This cybernetic mode also introduces novel questions of governance, ethics and technical politics. Who owns, controls or interprets these systems? What forms of life and labour are included, automated or rendered obsolete? What happens to urban accountability and collective agency in environments managed by black-boxed automation? Understanding cybersymbiotic and cyber-physical infrastructures requires critical attention to the infrastructures of computation themselves and their embedding within sociotechnical regimes of control, efficiency and optimization (Amoore, 2020; Safransky, 2020).

For example, in *Machine Habitus*, sociologist Massimo Airoldi (2022) examines how algorithms are shaped by a combination of culture and real-time learning in urban environments that integrate people, code and machines (from smartphones to robots). Of course, algorithms and digitality are nothing new to cities. What is new, Airoldi argues, is the autonomous and interactive dimensions of learning that accompany them today, and their sheer extent. Airoldi describes, for example, the IAQOS software piloted in Rome by engineer Salvatore Iaconesi and communication scientist Oriana Perisco. The open-source software was moved around the mixed multicultural neighbourhood of Torpignattara to ‘talk’ with residents, asking to be ‘taught’ words, stories and ideas. Over time, it developed ways of interacting with people that reflected that milieu. Its ways of speaking and answering questions, both in content and tone, were derived from the range of interactions it was engaging in. As Airoldi (2022: 33) writes, IAQOS ‘would have become a very different AI if it had been trained in the white and bourgeois Rome district of Parioli, with its tennis courts, private schools and high-class restaurants’. The digitalization and robotization of the infrastructure-environment presents new ‘cognitive assemblages’ (Hayles, 2017) around the politics and ethics of ownership, accountability, labour, knowledge and urban inequality.

#### – Neurotechnical infrastructures

A final complementary and emerging extension involves *neurotechnical infrastructures*, where the boundary between human cognition and technological infrastructure becomes increasingly porous (Williamson, 2017). These developments encompass neuro-sensing, brain-computer interfaces (BCIs) and affective computing, directly linking human perception, emotion and intention to technological systems (Garden *et al.*, 2016). This form of infrastructuralization is not simply about attempting to extend human capabilities but about integrating cognitive and neural processes into wider urban and digital environments, and in the process forging new economic, social and political spaces (Fitzgerald *et al.*, 2016; Adli *et al.*, 2017). Neurotechnical systems



can be found in various contexts, ranging from neural feedback in smart workspaces to biometric surveillance in public infrastructure, and affect-aware platforms that tune services based on users' emotional states. Such systems enable real-time feedback loops between bodies and infrastructures, where emotions, stress levels or neural signals can influence the operation of lighting, temperature, workflow or mobility services. In doing so, they enable a new frontier of infrastructural governance through the modulation of human interiority.

This is a fast-growing set of markets and technologies. Consider, for example, how companies utilize EEG-based headsets to enable users to control virtual and augmented reality environments through brain signals (e.g. *Neurable*), or use neurotechnology to monitor workers' attention, stress and engagement levels (e.g. *Emotiv*). Car companies are exploring similar technology with Brain-to-Vehicle (B2V) interfaces. At the same time, in Singapore there are experiments using sensors to capture facial expressions and body language on public transit, which are then used to alter ambient conditions, such as lighting, announcements or digital signage, to reduce crowd stress during peak times (e.g. *McStay*, 2018; *Agency for Science, Technology and Research*, 2022; *Li et al.*, 2022).

This raises profound questions about agency, autonomy, intentionality and consent. Who has access to the neural data that infrastructures act upon? What kinds of emotional or cognitive normativity are enforced? Neurotechnical infrastructures challenge the assumption of a discrete, autonomous subject, instead foregrounding relational and embodied entanglements between the brain, sensing environments and algorithmic protocols. As infrastructures increasingly reach into affective and cognitive registers, urban studies must grapple with the technopolitical consequences of the neural becoming infrastructural and the political economies of market development and control as part of a changing infrastructural landscape.

In summary, these extensions foreground the infrastructuralization of life itself partly at the level of provision or access, but primarily as modulation of sensation, cognition, emotion and survival. They blur conventional boundaries between infrastructure and subjectivity, technology and biology, human and non-human, social and economy. While analytically distinct, the extensions are deeply interrelated and collectively signal a shift towards an infrastructural politics concerned less with flow and connection than with differentiation, stratification and control.

### Diagnosing infrastructural modulation

We have outlined five key extensions of infrastructure and now collectively consider their shared implications for contemporary urban governance. While each domain operates through distinct materials, actors and mechanisms, together they reveal a transformation in how infrastructure governs life. This is not solely by providing access or support, but by modulating climate, sensation, emotion, cognition and ecological survival. These are infrastructures that act upon atmosphere, affect and thought, not as metaphors, but as operational realities.

These infrastructural extensions expose how contemporary infrastructure is increasingly implicated in the differentiation and stratification of urban life. Infrastructure, of course, never delivered services in a universalized fashion. But today, we see new ways in which it selectively optimizes some bodies, species, and spaces while bypassing or exposing others. This shift echoes earlier critiques of splintering urbanism but moves beyond them by extending infrastructural politics into new domains of life. As Table 1 summarizes, each extension introduces not only new materialities but also novel ethical, political and epistemological challenges for urban research.

First, across all five extensions, infrastructure appears not only as a technical or material formation, but also as a modulatory apparatus that selectively senses, adjusts and optimizes human and non-human life. In this sense, infrastructure operates through continuous feedback and anticipatory action, reconfiguring thresholds of exposure,

**TABLE 1** Urban implications of infrastructural extensions

| Infrastructural extension      | Urban political implications   | Key urban research directions   |
|--------------------------------|--|---|
| Elemental infrastructures      | Reframes atmosphere, water, temperature and chemical flows as governable media—creates new material regimes of urban inequality and extraction   | How do cities infrastructuralize climate and atmosphere? What forms of environmental justice or thermal violence emerge? How can governance account for planetary differentials?                              |
| Infrastructures of care        | Centers informal, affective, and relational labour as critical to urban life—challenges technocratic and masculinist planning logics             | How can care be supported without being instrumentalized? What infrastructures make care possible in crisis-ridden urban environments? What is the role of the state versus community in provisioning?        |
| Multispecies infrastructures   | Disrupts anthropocentric design paradigms—politicizes multispecies coexistence and ecological survival   | What ethical frameworks are needed for multispecies infrastructure? How do infrastructures support or suppress ecological diversity? How do non-human agencies reconfigure urban politics?                    |
| Cybersymbiotic infrastructures | Embeds algorithmic governance and automation into the urban fabric—redistributes control, responsibility and risk                                | Who designs and owns responsive infrastructures? How is accountability maintained in AI-mediated systems? What forms of urban subjectivity emerge in machine-inhabited environments?                          |
| Neurotechnical infrastructures | Blurs boundaries between cognition, affect and infrastructural systems—intensifies concerns over surveillance, consent and cognitive normativity | What are the political and ethical consequences of neurotechnology? How are cognitive and emotional states operationalized in urban systems? What alternative models of embodied infrastructure are possible? |

support and inclusion. These systems are not passive or neutral but deeply political, working through selective visibility, affective targeting and automated decision-making.

The second cross-cutting theme is infrastructural opacity. As infrastructures reach deeper into the affective and cognitive domains, they do so through opaque algorithmic systems, proprietary platforms and black-boxed sensing devices. This raises urgent questions around consent, intelligibility and agency, primarily where systems govern people they cannot see or understand. Such opacity is not merely technical, but political and economic, often reinforcing existing inequalities under the guise of optimization.

Third, these extensions exhibit a shared ambivalence. They are neither inherently emancipatory nor oppressive, but rather sites of experimentation and contestation. Care platforms, neural sensors or atmospheric modulation systems may simultaneously support life and exacerbate vulnerability, depending on their design, ownership and use. The extensions highlight how infrastructure becomes a volatile terrain of governance that enables some futures while foreclosing others.

Together, these extensions highlight how infrastructure is increasingly shaping the conditions of life itself, including its breathability, emotional range, ecological viability and cognitive experience. Rather than managing the background of urban life, infrastructure now delineates its very substance. In the following conclusion, we reflect on what this means for urban infrastructure studies and the conceptual, ethical and methodological shifts it must now navigate.

### Conclusion

The five infrastructural extensions explored in this essay do more than collectively challenge the conventional assumptions of urban infrastructure as fixed, backgrounded and bounded. These extensions expand infrastructure into new domains and also challenge its ontological basis. Extended infrastructure today governs the modulation of thermal environments, the management of interspecies life, the algorithmic orchestration of cities and the integration of neural and emotional states into responsive systems. These developments mark a shift in how infrastructure operates through its entanglement with the biological, ecological and cognitive dimensions of urban life.

We have argued that these extensions signal a fundamental transformation from infrastructure as the provision of services to infrastructure as the modulation of life. This shift entails an existential politics of infrastructure, in which the capacity to breathe, feel, survive or flourish becomes subject to infrastructural stratification. Contemporary extended infrastructures include air quality systems, caregiving platforms and neural interfaces that actively optimize, exclude and expose. These processes often occur through opaque socio-technical systems governed by narrow political and economic interests, producing new urban inequalities across bodies, species and spaces. In doing so, they trouble how we think about, define, conceptualize and research infrastructure, and one of our hopes here is that this piece provokes greater reflection on these imperatives.

Infrastructural extensions productively challenge urban infrastructure studies to expand their research priorities. First, they require interdisciplinary engagement, drawing on, for example, feminist care ethics, cognitive science, urban metabolism and platform studies. Second, they demand greater attention to the differentiated geographies of infrastructural power across the urban world. Third, they invite a re-examination of core infrastructural questions around inequality, sovereignty and the governance of life itself. Are these extensions simply intensifying splintered urbanisms, or are they—as we are suggesting—configuring a new mode of infrastructural biopolitics? What forms of urban futures do they enact and for whom?

Infrastructural extensions illuminate how infrastructure is no longer merely a substrate for stability and continuity. It has become a volatile and selective terrain of experimentation, governance and contestation. Rather than mitigate turbulence, infrastructure increasingly defines its contours, configuring the thresholds of liveability and exclusion. The challenge, then, is not only to conceptualize these extensions but to confront their consequences and to imagine infrastructural alternatives grounded in justice, reciprocity and collective care.

**Simon Marvin**, Urban Institute, University of Sheffield, Sheffield, UK,  
s.marvin@sheffield.ac.uk

**Colin Mcfarlane**, Department of Geography, University of Durham, Durham, UK,  
colin.mcfarlane@durham.ac.uk

**Jonathan Rutherford**, LATTs, Université Paris Est, Marne-la-Vallée, France,  
jonathan.rutherford@enpc.fr

## References

- Adey, P. (2013) Air/atmospheres of the megacity. *Theory, Culture and Society* 30.7/8, 291–308.
- Adey, P. (2015) Air's affinities: geopolitics, chemical affect and the force of the elemental. *Dialogues in Human Geography* 5.1, 54–75.
- Adli, M., M. Berger, E.-L. Brakemeier, L. Engel, J. Fingerhut, A. Gomez-Carrillo, R. Hehl, A. Heinz, J. Mayer, N. Mehran, S. Tolaas, H. Walter, U. Weiland and J. Stollmann (2017) Neurourbanism: towards a new discipline. *The Lancet Psychiatry* 4.3, 183–5.
- Agency for Science, Technology and Research (A\*STAR) (2022) *Sentiment analysis for public transport*. Institute of High Performance Computing (IHPC), Singapore [WWW document]. URL <https://www.a-star.edu.sg/ihpc/news/news/publicity-highlights/sentiment-analysis-for-public-transport> (accessed 26 August 2025).
- Airolidi, M. (2022) *Machine habitus: towards a sociology of algorithms*. Polity Press, Cambridge.
- Alam, A. and D. Houston (2020) Rethinking care as alternate infrastructure. *Cities* 100, 102662.
- Ali, S.H., C. Connolly and R. Keil (2023) *Pandemic urbanism: infectious diseases on a planet of cities*. Polity Press, Hoboken, NJ.
- Amoore, L. (2020) *Cloud ethics: algorithms and the attributes of ourselves and others*. Duke University Press, Durham, NC.
- Anwar, N. (2023) Introduction: the everyday politics of thermal violence in urban South Asia. *International Journal of Urban and Regional Research, Spotlight On: Extreme Heat in Urban South Asia* [WWW document]. URL <https://www.ijurr.org/spotlight-on/extreme-heat/introduction-extreme-heat-in-urban-south-asia> (accessed 26 August 2025).
- Arefin, M.R. and Prouse, C. (2024). Urban political ecologies of sewage surveillance: creating vital and valuable public health data from wastewater. *Transactions of the Institute of British Geographers*. Online first. <https://doi.org/10.1111/tran.12732>.
- Balayannis, A. (2020) Toxic sights: the spectacle of hazardous waste removal. *Environment and Planning D: Society and Space* 38.4, 772–90.
- Barns, S. (2019) *Platform urbanism: negotiating platform ecosystems in connected cities*. Palgrave Macmillan, London.
- Barua, M. (2021) Infrastructure and non-human life: a wider ontology. *Progress in Human Geography* 45.6, 1467–89.



- Barua, M. and A. Sinha (2023) Cultivated, feral, wild: the urban as an ecological formation. *Urban Geography, Urban Geography* 44.10, 2206–27.
- Brodie, P. (2020) Climate extraction and supply chains of data. *Media, Culture and Society* 42.7/8, 1095–114.
- Childs, Q. (2022) 'This has nothing to do with clouds': a decolonial approach to data centers in the node pole. *Commonplace* [WWW Document]. URL <https://doi.org/10.21428/6ffd8432.59c985d5>.
- Clark, A. (2018) *The poisoned city: flint's water and the American urban tragedy*. Metropolitan Books, New York, NY.
- Crawford, K. (2021) *Atlas of AI: power, politics, and the planetary costs of artificial intelligence*. Yale University Press, New Haven, CT and London.
- Engelmann, S. (2015) Toward a poetics of air: sequencing and surfacing breath. *Transactions of the Institute of British Geographers* 40, 430–44.
- Engelmann, S. and D. McCormack (2021) Elemental worlds: specificities, exposures, alchemies. *Progress in Human Geography* 45.6, 1419–39.
- Fitzgerald, D., N. Rose and I. Singh (2016) Living well in the neuropolis. *The Sociological Review* 64.1\_suppl, 221–37.
- Gandy, M. (2013) Marginalia: aesthetics, ecology, and urban wastelands. *Annals of the Association of American Geographers* 103.6, 1301–16.
- Gandy, M. (2021) Urban political ecology: a critical reconfiguration. *Progress in Human Geography* 45.5, 919–30.
- Gandy, M. (2022) The zoonotic city: urban political ecology and the pandemic imaginary. *International Journal of Urban and Regional Research* 46.2, 202–19.
- Garden, H., D.M. Bowman, S. Haesler and D.E. Winickoff (2016) Neurotechnology and society: strengthening responsible innovation in brain science. *Neuron* 92.3, 642–6.
- Ghertner, D.A. (2021) Postcolonial atmospheres: air's coloniality and the climate of enclosure. *Annals of the American Association of Geographers* 111.5, 1483–502.
- Graham, S. (2015) Life support: the political ecology of urban air. *City* 19.2/3, 192–215.
- Hall, S.M. (2020) Social reproduction as social infrastructure. *Soundings* 76.76, 82–94.
- Hayles, N.K. (2017) *Unthought: the power of the cognitive unconscious*. University of Chicago Press, Chicago, IL, and London.
- Hayles, N.K. (2021) Three species challenges: toward a general ecology of cognitive assemblages. In S. Lindberg and H.R. Roine (eds.), *The ethos of digital environments: technology, literary theory and philosophy*, Routledge, New York, NY.
- Jasper, S. (2020) Abandoned infrastructures and nonhuman life. Ecologizing infrastructure: infrastructural ecologies. *Society & Space Forum*, 30 November [WWW document]. URL <https://www.societyandspace.org/articles/abandoned-infrastructures-and-nonhuman-life> (accessed 26 August 2025).
- Keil, R. (2020) An urban political ecology for a world of cities. *Urban Studies* 57.11, 2317–33.
- Kitchin, R. & Dawkins, O. (2025) Digital twins and deep maps. *Transactions of the Institute of British Geographers* 50, e12699.
- Latham, A. and J. Layton (2022) Social infrastructure: why it matters and how urban geographers might study it. *Urban Geography* 43.5, 659–68.
- Li, R., T. Yuizono and X. Li (2022) Affective computing of multi-type urban public spaces. *PLoS One* 17.6, e0269176.
- Lorimer, J. (2020) *The probiotic planet: using life to manage life*. University of Minnesota Press, Minneapolis, MN.
- McCormack, D.P. (2017) Elemental infrastructures for atmospheric media: on stratospheric variations, value and the commons. *Environment and Planning D: Society and Space* 35.3, 418–37.
- McStay, A. (2018) *Emotional AI the rise of empathic media*. SAGE, London.
- Nowak, S. (2023) The social lives of network effects: speculation and risk in Jakarta's platform economy. *Environment and Planning A: Economy and Space* 55.2, 471–89.
- Otter, C. (2008) *The Victorian eye: a political history of light and vision in Britain, 1800–1910*. University of Chicago Press, Chicago, IL, and London.
- Peake, L. and M. Rieker (eds.) (2013) *Rethinking feminist interventions into the urban*. Routledge, London.
- Peake, L., N.S. Razavi and A. Smyth (eds.) (2024) *Doing feminist urban research: insights from the GenUrb project*. Routledge, London.
- Pollio, A., L.R. Cirolia and J. Ong'iro Odeo (2023) Algorithmic suturing: platforms, motorcycles and the 'last mile' in Urban Africa. *International Journal of Urban and Regional Research* 47.6, 957–74.
- Power, E.R. and M.J. Williams (2020) Cities of care: a platform for urban geographical care research. *Geography Compass* 14.1, e12474.
- Power, E.R. (2019) Assembling the capacity to care: caring-with precarious housing. *Transactions of the Institute of British Geographers* 44, 763–77.
- Power, E.R. and K.J. Mee (2019) Housing: an infrastructure of care. *Housing Studies* 35.3, 484–505.
- Safransky, S. (2020) Geographies of algorithmic violence: redlining the smart city. *International Journal of Urban and Regional Research* 44.2, 200–18.
- Simone, A.M. (2004) People as infrastructure: intersecting fragments in Johannesburg. *Public Culture* 16.3, 407–29.
- Simone, A.M. (2021) Ritornello: 'people as infrastructure'. *Urban Geography* 42.9, 1341–8.
- Stamatopoulou-Robbins, S. (2019) *Waste siege: the life of infrastructure in Palestine*. Stanford University Press, Stanford, CA.
- Strauss, K. and F. Xu (2018) At the intersection of urban and care policy: the invisibility of eldercare workers in the global city. *Critical Sociology* 44.7–8, 1163–78.
- Ujikawa, T. (2025) Convenience stores as care infrastructure for older adults: the crisis of care in Tokyo, Japan. *International Journal of Urban and Regional Research* 49.1, 183–203.
- Urry, J. (2016) *What is the future?* Polity Press, Cambridge.
- Velkova, J. (2016) Data that warms: waste heat, infrastructural convergence and the computation traffic commodity. *Big Data & Society* 3.2, 2053951716684144.
- Williamson, B. (2017) Computing brains: learning algorithms and neurocomputation in the smart city. *Information, Communication & Society* 20.1, 81–99.
- Wilson, H.F. (2022) Seabirds in the city: urban futures and fraught coexistence. *Transactions of the Institute of British Geographers* 47.4, 1137–51.
- Zellmer, A. and B. Goto (2022) Urban wildlife corridors: building bridges for wildlife and people. *Frontiers in Sustainable Cities* 4, 954089.