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1. Researching infrastructures and cities: origins, debates, openings

Olivier Coutard and Daniel Florentin

AN EXTENDED INFRASTRUCTURAL REALM

A number of scholars within the social sciences have remarked that we are in the midst of both an ‘infrastructural moment’ – with massive symbolic and financial investment in, especially, energy, digital and transport infrastructures – and an ‘infrastructural turn’ – with a growing and increasingly diverse use of the notion in various research areas (see, e.g., Amin, 2014; Howe et al., 2016; Harvey et al., 2016; Chatzis, 2017; Jarrige et al., 2018; Lawhon et al., 2018; Pike et al., 2019; Addie et al., 2020).¹ Indeed, infrastructures have been at the forefront of major and interrelated transformations for several decades, from the intensification of global environmental changes (such as climate change) and responses to these changes to the ongoing, multifaceted ‘digital transition’, through accelerated processes of urbanisation, and increased economic and metabolic² globalisations. This context has fuelled a renewed interest in infrastructures in public and academic debates.

This *Handbook of Infrastructures and Cities* reflects and builds on this context. It is rooted in an intellectual tradition born from various sources in western Europe and North America in the early 1980s. In this tradition, the term ‘infrastructure’ has, until recently, referred specifically to the large technological networks developed to ensure, especially, energy and water supply, waste and wastewater collection and treatment, and transportation and communications services that underpin the functioning of contemporary economies, societies, cities and territories. As such, infrastructures are conceived as material expressions of sociopolitical choices and organisations, which they in turn contribute to shape. Like the French word *réseau*, with which it has a close affinity, the notion of infrastructure emerged as a new analytical category joining together technological domains that had hitherto mainly been studied separately – with the ambition to shed new light on the social meaning and significance of such large-scale technological constructs.

Over the past four decades, the understanding of the many facets of infrastructures has been considerably enriched through a variety of approaches, ranging from history of technology to

¹ The authors wish to thank participants to the *Handbook* authors’ workshop in Turin (Italy) in June 2022 for their valuable feedback on an earlier draft of this introduction, as well as Jean-Paul Addie (who was also in Turin), Sabine Barles, Kathryn Furlong and Jonathan Rutherford, who agreed to read and comment on an extended draft in spite of a (very) short deadline.

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² The terms metabolism and metabolic refer here to flows of energy and matter, which must be distinguished from financial flows – even when the former are directly related to the latter.

urban planning, from social studies of technology to the anthropology of everyday life, from industrial economics to political ecology... This diversity of approaches has increased over time, accompanying the expansion of infrastructure studies to urban contexts in all regions of the world. It has also been concomitant with changes in research questions and perspective and with the diversification of what can be regarded, conceptualised and analysed as infrastructure. In line with these changes, ontological discussions have become substantial within infrastructure studies since the turn of the century.

Since the late 1990s and early 2000s, the term has thus departed from the sole analysis of technological networks or systems and has been increasingly employed to refer to various material or immaterial phenomena. Uses of the notion of infrastructure in humanities and social sciences can be loosely grouped into five broad streams: (1) studies of technopolitics, i.e. of the relations between technology-based interventions and power or domination schemes (see, e.g., Barry, 2001; Mitchell, 2002; von Schnitzler, 2008; Collier, 2011); (2) explorations of the material dimension of ‘knowledge work’ (Bowker, 1994; Star and Ruhleder, 1996; Bowker and Star, 1999) in scientific research and other activities, or of the systemic dimension of (especially computer-based) information technologies (Edwards, 1998a; Karasti et al., 2010); (3) studies of alternative forms of social organisation ‘capable of facilitating the intersection of socialities so that expanded spaces of economic and cultural operation become available to residents of limited means’ (Simone, 2004, p. 407) in contexts where technological infrastructures are failing; (4) infrastructures as the intermediary between resources and consumption patterns (Van Vliet et al., 2012), and as such, an essential component of social metabolism (Krausmann et al., 2008; Barles, 2015) and a key driver of environmental changes during the two last centuries; and (5) infrastructure as a metaphor for entire ecosystems (Frischmann, 2012; Cardoso da Silva and Wheeler, 2017).

Beyond transfers of concepts or issues across infrastructure sectors, a number of authors have also argued for transfers of methodologies, such as multi-sited ethnography (Silvast and Virtanen, 2019), or the use of studies, narratives or even metaphors of infrastructure as ‘middle-range methodology’ (Hine, 2007) to explore other social phenomena. In his influential survey of the uses of the notion of infrastructure in recent anthropological research, Larkin (2013) thus notes that ‘for years anthropology has played with the metaphor of infrastructure to refer to everything from Marxist analyses of base/superstructure relations to Saussure’s langue/parole distinction, to any system that appears to underlie and give rise to the phenomenal world (culture, episteme, social structure)’ (p. 328). Larkin then more specifically argues that in anthropological research on ‘technopolitics’, ‘infrastructures are interesting because they reveal forms of political rationality that underlie technological projects and which give rise to an “apparatus of governmentality” (Foucault)’ (ibid.). In a similar vein, Angelo and Hentschell (2015) argue that, because ‘small-scale interactions with infrastructure are, literally, foundations of larger scale social forms’ (p. 306), ‘interactions with infrastructures’ can be used as ‘windows into social worlds’ and even as ‘a method for critical urban studies’, by ‘allow[ing] scholars to literally connect the dots between very different experiences and places to make sense of broader social developments’ (p. 307).³ These ‘dots’ can take various forms. For example, Baumann (2018) notes that ‘infrastructures link various layers of the city: past spatial arrangements with plans for the future, the human with the non-human, the intimate

³ On infrastructure as method, from a complementary perspective, see Cowen (2020).

with the geopolitical' (p. 152). In a way, this implies to consider, after Rutherford (2020), infrastructure as a 'lens' or as a 'key site' to analyse the 'ongoing and contested process of making sustainabilities/futures' (pp. 2, 8–9), and thus as an arena where current ecological crises and their handling can be observed. In other words, 'the main task of infrastructure is to present the future' (ibid., p. 4).

The notion of infrastructure, then, does not only designate 'things and also the relation between things' (Larkin, 2013, p. 29), or networked technological constructs bringing modern living conditions to as many people as possible. Conceived as a tool of both alienation and emancipation, it has become a revealer of contested processes of production and reproduction of forms of coercion, injustice or violence in social arrangements, and as such a key notion in critical social sciences. In the words of Rodgers and O'Neill (2012b, p. 402):

infrastructure emerges as an ideal ethnographic site for theorizing how broad and abstract social orderings such as the state, citizenship, criminality, ethnicity and class play out concretely at the level of everyday practice, revealing how such relationships of power and hierarchy translate into palpable forms of physical and emotional harm. ... At the same time, however, infrastructure is ... also a potential place for imagining more positive politics.

Contributions to this *Handbook* to some extent follow the notion of infrastructure in its various meanings and uses and seek to account for the ways in which these variegated conceptualisations interact and shape one another. The chapters more specifically explore: (1) the sometimes profound transformations of 'traditional' networked infrastructure systems; (2) the conversion of parts of the material environment into infrastructure, or their categorisation as infrastructure – what is referred to in this volume as *infrastructuring*; (3) the broader social changes simultaneously shaping and shaped by infrastructural change; and (4) the shifting roles of infrastructures with regard to human societies' pressures on the biosphere. The exploration of these transformations, and the sometimes heated debates that surround them, contribute to better addressing research and policy challenges relating to contemporary infrastructural, urban and societal change across North and South.

This introduction aims to locate the book in its epistemological context and to expose the intentions of the collective of authors involved. In order to do so, we first provide an overview of the diverse genealogies of infrastructure research. Second, we offer an account of the current intellectual landscape in the field, highlighting four broad themes that correspond to the four parts of the book. The book chapters provide in-depth discussions of 'hot topics' in the field, generally accompanied by short vignettes of cases illustrating the chapter's argument.

The book as a whole is a contribution to a thriving research area. More than a definitive sum on urban infrastructure research, this *Handbook* has been conceived as a forward-looking snapshot of an abundant, heterogeneous and very dynamic stream of scholarship. The process of production of the book was designed to best grasp that dynamic as well as to allow for the maximal diversity among contributors in terms of intellectual sensibility, disciplinary background, advance in career and sociopolitical concerns. At the same time, we sought to achieve a consistent set of contributions through a genuinely collective elaboration process.⁴

⁴ The book largely benefited from the organisation of two authors' workshops, one in Fontainebleau in September 2021 and one in Turin in June 2022, during which the structure of the book and successive versions of each chapter were collectively discussed.

ORIGINS AND HYBRIDISATIONS: A KALEIDOSCOPIIC GENEALOGY OF INFRASTRUCTURES

In the early 1980s, some historians and social scientists nearly all based in western Europe and North America took novel interest in infrastructure systems. There had of course been earlier work on specific infrastructures, in engineering primarily but also in urban and technological history and in planning. But there had been no significant attempt to consider these infrastructure domains as a consistent whole and the notion of infrastructure as a relevant analytical category.⁵ This novel research object emerged in a specific historical context characterised by a combination of massive material and sociopolitical transformations (see Box 1.1), leading to the analysis of infrastructures as fundamentally *social* phenomena.⁶

As such, the then emerging ‘infrastructure studies’ shed light on the articulations between infrastructural change and other forms of social change broadly construed, exemplifying the threefold nature of infrastructure as a technology, an analytical category and a metonymic reference to modernity (at least, a certain modernity) altogether (Calhoun, 1992; Edwards, 2003).

BOX 1.1 THE NOVEL TOPICALITY OF ‘INFRASTRUCTURES’ IN THE 1980s

Pioneering contributors to (what we refer to here as) infrastructure studies evoked various historical circumstances that contributed to placing infrastructure sectors as a whole at the forefront of public and academic agendas, in particular:

- *A transformation in the planning culture*, associated with specific infrastructural developments such as ‘the extraordinary development of transport and, especially, communications, conceived and planned as networks, [which requires to consider] the network as a spatial planning principle, which articulates technological possibilities and the service of a territory’ (Dupuy, 1985, p. 6; see also *Annales de la recherche urbaine*, 1984).
- *A technological transformation, in particular through the rise of information technologies*, which were soon perceived as a common factor of change across infrastructure sectors: ‘the key technological issue for urban technological networks resides in the fallouts of the information revolution, not only because of the emergence of new,

⁵ With the important exception of economic and legal analysis of ‘natural monopolies’ and ‘public utilities regulation’ (e.g., Posner, 1969).

⁶ In our discussions of infrastructures as social phenomena, we will seek to comply with Joerges’s (1988) wise advice to systematically qualify the social in science and technology studies, so as to escape the misleading dichotomy between ‘the technological’ and ‘the social’ (as also emphasised by actor-network theory). According to Joerges, ‘the term “social” should, if possible, be used as an umbrella term only [thus also encompassing technical social phenomena]. Non-technical social phenomena (organizations, institutions, interactions, etc.) should be specified separately’ (Joerges, 1988, p. 19). Infrastructures obviously display specific properties due to their material, or technological dimension. In particular, we share MacKenzie and Wajcman’s view that ‘the material world is not a simple reflection of human will, and ... one cannot make sense of the history of technology if the material world is seen as infinitely plastic and tractable’ (MacKenzie and Wajcman, 1999, p. 24).

fast-developing networks, but especially because of the possibilities to deeply transform the design and operation of other [existing] networks' (Martinand, 1986, p. 252).

- *A growing concern (especially among environmental historians and historians of technology) for the environmental implications of urbanisation and urban infrastructures*, which pointed to the central role of (urban) technology (understood here as infrastructure) in the organisation and expansion of cities hence as a driver of the urban growth machine and as major sources of pollution and health threats (Melosi, 1990).
- *A transformation in regulatory frameworks and practices, in relation with the implementation of liberalization agendas internationally*, which progressively affected all infrastructure sectors previously regarded and regulated as 'natural monopolies'. As observed by Graham and Marvin in Britain, for example, 'in the 1970s, the media ignored utilities. ... Today, however, utilities are big news. The behaviour of British Gas, the electricity companies, British Telecom (now called simply BT) and the water companies now routinely fill a sizeable portion of the UK media. TV utility specials are common. Why this remarkable transformation? The reason is, of course, the privatization and the liberalization of utilities in the 1980s' (Graham and Marvin, 1994, p. 113).
- In a related movement, *a transformation of the welfare state and a neglect of existing public infrastructures, leading to infrastructural crisis and infrastructural vulnerability*, characterised, for instance, by 'a growing consensus about a nationwide problem [in the USA] with the adequacy and maintenance of the nation's infrastructure, specifically with urban public facilities' (Hanson; 1984, p. 1; see also Choate and Walter, 1983). Similar manifestations of that crisis are observed in the English context: 'following the considerable decline in public capital expenditure over the last decade ... the state of the physical fabric of the nation is arousing concern' (Cowie et al., 1984, preface).

In this context, the term 'infrastructure' (first in the singular, then increasingly in the plural) was gradually emancipated from its Marxian origins.⁷ Indeed, the notion of infrastructure as used by urban historians, planners and large technical systems (LTS) scholars does have commonalities with its Marxist cousin, insofar as both traditions emphasise its material dimension and its political significance, and use the term to refer, if only metaphorically, to the material and social base upon which society 'functions'. But, as we will see, scholars within what is becoming the area of infrastructure studies emphasise a number of distinctive dimensions of infrastructures, in particular their technological dimension, their systemic and networked

⁷ For Marxists (although it seems that Marx himself never used the term, preferring that of 'base'), the infrastructure (in the singular) refers to the ensemble formed by the means of production and the social relations of production prevailing in a given society. It is distinguished from the superstructure (a term that Marx did use), which designates the political, legal and ideological organisation of that same society.

In particular, the highly influential economic geographer David Harvey uses the notion of physical and social infrastructures (in the plural) in a relatively orthodox Marxist way. In *The Limits to Capital* (1982), where he seeks to provide 'a definitive statement on the urban process under capitalism from a Marxist perspective' (Harvey, 2006 [1982], p. xxix), he notes, rather conventionally, that 'long-lasting and often immovable social and physical infrastructures ... are required to facilitate the production of labour power of a certain quantity and quality' (p. 383). When Harvey singles out physical infrastructures, he illustrates the notion with examples of transport facilities or 'networks', e.g., 'docks and harbours, transport systems and so on' (p. 226) or 'roads, railways, canals, airports, etc.' (p. 380).

character, their role in the provision of essential services, and their importance in the conduct of everyday life beyond work and production.⁸ In short, they foster a dominant use of the term ‘infrastructure’ to designate a broad ensemble of networked technological systems

In this section, we first briefly explore the origins of urban infrastructure studies in the 1980s (1), before examining three important shifts in dominant debates within this research domain in subsequent decades: (2) the critique of the ‘modern infrastructural ideal’ and of the metonymic assimilation of ‘modernity’ to the general availability of services provided by centralised networked infrastructures; (3) an ‘infrastructural inversion’, foregrounding infrastructural practices and processes of infrastructuring; and (4) the belated environmentalisation of urban infrastructure studies.

The Urbanisation of the Infrastructural Question

Research on infrastructures and cities has its roots in the unplanned hybridisation, in the 1980s and early 1990s, of three main research streams sharing an interest for the social and material dimensions of technology: ‘new urban history’, work on territorialities of technological networks and studies of LTS. This interdisciplinary cross-fertilisation led to the emergence of now well-recognised notions such as networked urbanism.

Technology and the ‘new urban history’

In an early historiographical survey of ‘the evolution of the urban infrastructure in the nineteenth and twentieth centuries’ in the United States, Joel Tarr (1984a) defines the ‘urban infrastructure’ as ‘the ‘sinews’ of the city: its road, bridge, and transit networks; its water and sewer lines and waste disposal facilities; its power systems; its public buildings; and its parks and recreation areas’ (p. 4). Four years later, in their seminal edited volume, Joel Tarr and Gabriel Dupuy use a similar definition, although this time limited to technological networks, and insist on the pivotal role of infrastructure in the functioning of the urban:

Technological infrastructure makes possible the existence of the modern city and it provides the means for its continuing operation. (Tarr and Dupuy, 1988, p. xiii)

This echoes Ausubel and Hermann’s (1988) definition of urban infrastructure as cities’ ‘vital systems’. They describe them as ‘large-scale engineering systems [that] include a variety of public works, such as roads, bridges, and sewer systems, as well as privately managed utilities such as electric power and telephone service’ (p. v).

The genealogy of infrastructures, for these authors, combines civil engineering, public works and (urban) utility services. Joel Tarr, Mark Rose and Joseph Konvitz (1990) offer a useful ‘evolutionary’ perspective on historical research on ‘technological networks and the American city’. They argue that, until the 1970s, the dominant paradigm in studies of

⁸ ‘Infrastructure refers to those economic activities which enhance, directly or indirectly, output levels or efficiency in production. Essential elements are systems of transportation, power generation, communications and banking, educational and health facilities, and a well-ordered government and political structure’ (Katz, 1982). Note that the Marxist notion of infrastructure has been extensively used by economists studying, in particular, national or regional development, before it gradually shifted to designate public utilities (or their public works component) and technological networks more generally (e.g., Eberts 1986, 1990; Aschauer, 1989).

technology and urban change considered that cities were malleable to technological change (especially change in transportation technologies). In the late 1960s and early 1970s, historians of the ‘new urban history’ movement (Hershberg, 1978) sought to provide more ‘recursive’ accounts of how technological change and urban change mutually shaped each other. Various public works and utility sectors, grouped under the novel notion of technological networks, became a privileged empirical category in the study of the relationship ‘between urban spatial and social change on the one hand and technological change on the other’ (Tarr et al., 1990, p. 88). As a result, more studies considered a set of technological networks rather than a single technology. Tarr et al. cite in particular the early works by Warner (1962, 1972), Platt (1983), Armstrong and Nelles (1986), Ausubel and Hermann (1988) and Keating (1988), in addition to Tarr’s own contributions.

Melosi (1990) discusses the specific insights produced by these approaches. Importantly enough, from a contemporary perspective, they emphasised the negative side-effects of urban sanitation (especially sewerage and waste disposal);⁹ they also highlighted the contingent impact of technological networks on urban development and its dependence on complex decision-making systems and processes;¹⁰ and they recommended studies of the delivery of broadly defined societal functions rather than studies centred on a single technology (on the implications of this, see also Schott, 2004 and Bocquet, 2006). It is fair to say that, apart from historians, the emerging community of infrastructure studies largely ignored these insights and recommendations for a couple of decades at least.

The French *réseaux* group and research on the territoriality of technological networks

Early contacts were established between the North American ‘new’ historians of urban technology and a group of French scholars, some of them urban technology historians as well, sharing their interest for technological networks and a joint conference on ‘The City and Technology’ was organised in Paris in December 1983 (*Annales de la recherche urbaine*, 1984; Tarr and Dupuy, 1988). Indeed, in the early 1980s, the *groupe réseaux*, an interdisciplinary group of scholars (primarily from the humanities, planning, social sciences and economics) promoting the study of territorial technological networks (*réseaux techniques territoriaux*), was emerging in France on the initiative of, in particular, Gabriel Dupuy.¹¹ The *groupe réseaux* was interested in the same range of civil engineering and public utility sectors as the North American group of historians, although with a contemporary rather than a historical focus. Interestingly, the term infrastructure was soon used by scholars like Dupuy as

⁹ ‘While city-wide sewer systems alleviated sanitation problems of the inner city, they often redirected waste to nearby rivers, lakes and bays, thus creating a new set of health and pollution hazards’ (Melosi, 1990, p. 47).

¹⁰ Stressing the need for a common conceptual framework for such studies, Christine Rosen (1986) proposes that ‘at the simplest, most abstract level, the process of infrastructural improvement can be construed as a three-dimensional relationship between (1) the economic and demographic growth stimuli provoking improvement, (2) the adaptive modifications or extensions of the infrastructure necessitated by the stimuli, and (3) a wide variety of frictions that mediate that stimulus/response relationship’ (p. 221).

¹¹ The academic journal *Cahiers du groupe réseaux* started to appear in 1985: www.persee.fr/collection/flux.

the English translation of *réseau*.¹² Thus, in the special issue ‘Les réseaux techniques urbains’ (*Annales de la recherche urbaine*, 1984), he asks: ‘why in the Occidental cities did many networks take the shape of concrete technical devices, of technologies making very soon an urban “infrastructure?”’ (p. 269). Initially used in the singular, it quickly became a plural form (‘infrastructure networks’, Dupuy, 1987, p. 175), analysed within a systems theory paradigm (Dupuy, 1985).

The territorial perspective was central in the *groupe réseaux* from its inception. The group emphasised in particular: (1) spatial heterogeneity as a factor of development of technical networks; (2) the multi-scale or trans-scalar dimension of technological networks; (3) the dialectic relation between the ‘functional spaces’ served by networks and the ‘institutional territories’ administered by national states or local governments; and (4) the superposition of increasingly dominant forms of *networked territoriality* based on a general principle of connection at a distance (associated with network development) and forms of *areal territoriality* based on spatial proximity that prevailed traditionally.

Other European countries also developed pioneering multi-sectoral approaches in planning and urban studies. This was observed in Sweden (Svedinger, 1991) and in the UK under the impetus of, in particular, urban scholars from the University of Newcastle (e.g., Marvin, 1992; Marvin and Graham, 1993; Graham and Marvin, 1994; Guy et al., 1997), who created the Centre for Urban Technologies in the same university in the early 1990s.

Infrastructures without a city perspective: the LTS group

A third interdisciplinary research stream emerged in the 1980s: the so-called LTS group, bringing together scholars from the history of technology, social studies of technology and political science (primarily based in North America, western Europe and Australia). Scholars of this group emphasised the systemic and social nature of technology, in the wake of Thomas Parke Hughes’s extremely influential *Networks of Power* (Hughes, 1983). As Hughes noted in the preface to the book, reflecting on the history of technology, and in striking resonance with the ‘new urban history’ agenda: ‘I found that there was interest in the impact of technology on society, but that with rare exceptions the impact of society, or culture, on the shape of technology had been virtually ignored’ (p. x). And a few pages later, he further specifies the book’s approach and ambition: ‘This book is not simply a history of the external factors that shape technology, nor is it only a history of the internal dynamics of technology; it is a history of technology and society’ (p. 2).

Although concerned with other sorts of ‘big technology’ at times, LTS research predominantly focused on ‘spatially extended and functionally integrated socio-technical networks’ (Mayntz and Hughes, 1988, p. 5); and even though, especially in early LTS writings, the term infrastructure was seldom used,¹³ the proximity of the notions is hardly debatable. Thus Joerges (1988), in a programmatic chapter on future LTS research introducing the first volume in the LTS series, examines the implications of ‘moving up’ from the general category of hazardous technology ‘to large technical infrastructures and support systems (LTS in the sense advocated here)’ (p. 23). In the same text, Joerges offers an often-cited generic definition of LTS: ‘those complex and heterogeneous systems of physical structures and complex machin-

¹² Historical studies suggest that the two terms share similar origins in civil and military engineering (Guillerme, 1986; Carse, 2017).

¹³ It is, for example, not even listed in the index of Hughes’s *Networks of Power* (1983).

eries which (1) are materially integrated, or “coupled”, over large spans of space and time, quite irrespective of their particular cultural, political, economic and corporate make-up, and (2) support or sustain the functioning of very large numbers of other technical systems, whose organisations they thereby link’ (Joerges, 1988, p. 24). In his and other LTS scholars’ use of the term, infrastructure often refers specifically to the material layer (‘subsystem’) of (networked) LTS, in other words the pipes, conduits, tracks, lines or wires that are a constitutive and, indeed, distinctive part of such systems.

Whether or not the term ‘infrastructure’ was used, the LTS literature participated in forging the now widely accepted idea that there is analytical value in considering a variety of ‘infrastructure systems’ as belonging to a common category. The agenda of the group was indeed to ‘carry’ concepts and research questions from one sector to another,¹⁴ as well as to examine their common properties and the significance of the combined development of various LTS.

In spite of its lack of urban or territorial focus, the LTS agenda turned out to play an important role in the shaping of urban infrastructure studies. Within a few years at the turn of the 1980s and the 1990s, the LTS group published several edited volumes, offering a new perspective on large technology and setting up a novel interdisciplinary research agenda. LTS research addressed issues pertaining to both the internal workings of the said systems and the functioning of the societies in which these systems had come to develop or were developing. These issues included: patterns of infrastructure development (Hughes, 1983; Mayntz and Hughes, 1988; see also Bijker, Hughes and Pinch, 1987); control and management of big technology, especially in relation to risk and safety issues (La Porte, 1991); change and reconfiguration in large systems (Summerton, 1994); governance issues; public regulation challenges; and the governability of LTS (Coutard, 1999). Discussions on design, standards and norms; ‘momentum’ and reconfiguration; control and its often contested centralisation; state-building and its relation to big technology;¹⁵ etc., cut across all LTS conferences and edited volumes.

Infrastructures and *réseaux*: cross-sector notions expanding beyond material arrangements

Conceptualisations of infrastructure and *réseau* as cross-sectoral analytical categories¹⁶ in the abovementioned three research areas (urban technologies, *réseaux*, LTS) were enriched through mutual influence. Historians of urban technologies brought the *longue durée* perspective to the study of the relations between technological change and urban social and spatial change. *Réseaux* scholars elaborated upon a relational understanding of space and territorial-

¹⁴ Consider Renate Mayntz’s foreword to Mayntz and Hughes (1988): ‘This volume’s table of contents had been planned beforehand and authors were approached to write on particular subjects, answering a set of leading questions. It was clear, moreover, that the model of systems development spelled out in *Networks of Power* would serve as a general reference point, even where no explicit comparison ... was attempted’ (p. 6).

¹⁵ Cf. Mayntz (1993). Distinct, but similar arguments, are made by Mann (1984) with his notion of ‘infrastructural power’ which designates ‘the capacity of the state to actually penetrate civil society, and to implement logistically political decisions throughout the realm’ (p. 189); and Mukerji (2010), who has, with her notion of logistical power, ‘drawn attention to the fundamental ways modern states with their obligations of stewardship and their material infrastructures enroll natural forces into political life’ (p. 419).

¹⁶ Let us insist that this ‘epistemological move’ was not self-evident in the late 1970s and early 1980s, and fuelled lengthy scholarly discussions at the time (see, for example, Dupuy, 1988).

ity, and its implications for urban studies. LTS scholars emphasised issues of control, politics and the state. This process of ‘cross-fertilisation’ was facilitated by the setting up of various arenas such as *Flux*¹⁷ and the *Journal of Urban Technology*, two academic journals founded respectively in 1990 and 1992¹⁸ and specifically addressing infrastructure issues, the series of edited volumes on LTS, and a number of dedicated conferences regularly organised since the early 1990s.

In this process, research on infrastructures/networks was considerably enriched. At the same time, it is important to note that the notion of infrastructure prospered in research conversations and areas that were, and still are, not primarily concerned with space, territorial or urban theory – especially in economics, management and organisation studies. In particular, Curien (1992) proposed a three-layer economic model to depict networked infrastructures as the combination of a material base (*réseau-support*), an intermediary layer of information and control systems (*réseau de commande*) and final use services (*réseau-service*). Although essentially aspatial, Curien’s model proved extremely valuable in subsequent conceptualisations of the notion of *réseau*. For example, Offner (1993) extended Curien’s model to propose an evolutionary, space-sensitive model of infrastructure development, composed of five ‘layers’, namely a morphological one (the layout of the tracks, lines, or conducts), a material one (‘hardware’), a functional one (services), a regulatory one (the operating system) and a territorial one (topology of places, or points in space, connected by the network).

As it was appropriated by organisation studies, the notion of *réseau*, beyond an analytical category, also became an analytical tool, a *method*, to foreground processes and functions of intermediation or interfacing between suppliers and users (Curien and Gensollen, 1992); between places or across spatial scales; between individual agents and structures (including through its contribution to the structuration of actor-networks); between various temporalities, from real time to decades and even centuries; etc.

The urbanisation of research on territorial networks and infrastructures

This conceptualisation of infrastructure as a dynamic multi-layer construct allowed a new understanding of processes of ‘metamorphosis’¹⁹ (Chatzis, 2017, p. 26ff.) of infrastructure systems; of the role of technology in institutional, spatial and broader social organisation (Moss, 2020); of the forms, scales and means of social control; etc. It was also (re)imported in spatial studies to theorise change in socio-spatial organisation or the dynamics of urban forms, scales and systems (e.g., Offner and Pumain, 1996).

Indeed, in the wake of the emergence of the notion of infrastructure as an analytical category across a variety of technological domains and its ever-closer alignment with the notion of territorial technological network, an *urban* infrastructure research stream gradually emerged. This ‘urbanisation’ of an important share of infrastructure research can in a way be seen as contingent, as an outcome of the field’s dominant origins and the result of early work on tech-

¹⁷ A mostly French-language ‘international scientific quarterly on networks and territories’. www.cairn.info/revue-flux.htm.

¹⁸ Later followed by the Routledge Networked Cities book series (2003–2012) and the MIT Press Infrastructures book series (founded in 2010).

¹⁹ Chatzis uses the term metamorphosis to characterise the dominant pattern of infrastructural change, which combines at times profound evolutions in some dimensions (or layers) with stability in others, thus maintaining a form of identity along the way (see also Offner, 1993).

nological networks or in cities by leading researchers in the field with a planning or an urban history background (e.g., Tarr and Dupuy, 1988; Dupuy, 1991; Graham and Marvin, 1996, 2001). But there are at least two more fundamental reasons.

The first relates to the historical importance of technological networks in the development of cities and urban management in long-industrialised countries and the ‘rise of the networked city’ since the mid-nineteenth century, which cannot be dismissed as the biased view of city-centred scholars (see, e.g., de Swaan, 1988 and Hård and Misa, 2008 for western Europe). These historical circumstances are essential to understand and account for the emergence in industrial, policy and academic circles of the ideal of the networked city (cf. Box 1.2).

BOX 1.2 SYNTHESISING THE CHARACTERISTICS OF THE NETWORKED CITY

- Ubiquitous network infrastructures and services; and associated values and principles (supply-oriented, planned for growth, materialising a linear metabolism, emphasising flows over resources...)
- Network ideology (universal reticulation, spatial extension, organisational expansion, sophistication, security through redundancy) and supply-side ideology (infrastructure and service provision, limited consideration of demand/use/consumption/practices)
- Homogeneous infrastructural spaces (of provision), norms, conventions, expectations, hence the quest for a universal access to network
- Urban citizenship through ‘network citizenship’ (including ideas of solidarity through use, subscription to collective service...)
- Strong regulatory presence of: public providers of essential services, public oversight of (especially privately owned) providers, welfare state and revenue redistribution, control on urban development

Source: Coutard and Rutherford, 2016, p. 5.

The second reason is a gradual re-conceptualisation of the urban, distinct both from understandings of the premodern city as primarily structured by considerations of land ownership and use (Bassand, 1983) and from conceptualisations of the city *à la* Chicago school as large, dense and diverse concentrations of population (and activities). In contrast, the acknowledgement of the growing importance of technological networks in the organisation of space supported the development of a relational understanding of the urban.

Admittedly, it had long been recognised that the development of exchange and (especially economic) relations lie at the heart of the urbanisation process, both within cities among increasingly large and diverse numbers of city-dwellers (and among specialised activities or crafts), between urban centres and their hinterland, and between cities on ever-larger spatial scales.²⁰ Yet the implications for spatial planning had only been perceived by a few professionals and the significance for the conceptualisation of space had not been substantially attended to.

²⁰ See, e.g., Mumford, 1961, chapter 4 (The nature of the ancient city), esp. p. 94 sq ‘Development of urban functions’ and p. 102 sq. ‘Urban division of labour’.

As early as 1985, advocating for a systems' approach in urban studies that would acknowledge the central role played by technological networks, Dupuy notes that 'a quasi-physical understanding of the urban object, of the building, of the built environment, of zoning ... disappears and makes way for a relational understanding' (Dupuy, 1985, p. 48). The acknowledgement of the growing importance of relational forms of territoriality and the promotion of a relational understanding of space and territoriality (Raffestin, 1980; Massey, 1985, 1992) was not limited to urban 'objects': it applied to all spaces and scales, disrupting the notions of scale and (areal) space themselves. 'The question is to analyse these networks, regardless of their sectors, not only as technologies for transportation, food supply or communication, but also as modes of territorial solidarity, synchronisation and organisation' (Dupuy, 1985). Dupuy (1991) opposes *networked urbanism*²¹ to the zoning principle underpinning much traditional urban planning and bolstered by the 'Modern Architecture' movement and (Le Corbusier's) *Athens Charter*. In a similar vein, Graham and Marvin (1996) emphasise the role of 'telematics' in the ascent of novel forms of spatiality, noting that 'physical proximity has very little to do with electronic proximity or access' (p. 383) and emphasising the need 'to reconfigure urban studies and urban policy-making in ways which directly reflect the increasingly tele-mediated nature of contemporary cities' (p. 384).

This importance of a relational understanding of space for urban studies and the role played by (urban) technological networks is thus asserted by Stephen Graham and Simon Marvin in their two books published at the turn of the century. In chapter 2 ('A paradigm challenge') of *Telecommunications and the City* (Graham and Marvin, 1996), they note that 'through telecommunications and innovations in rapid transportation, relations between the physical and locational aspects of cities and the operation of social and economic systems are being fundamentally loosened and reworked' (p. 49).²² In *Splintering Urbanism*, they extend the analysis to all 'infrastructure networks', described as 'the key physical and technological assets of modern cities. ... In fact the fundamentally *networked* character of modern urbanism ... is perhaps its single dominant characteristic' (p. 10; their emphasis). Through this, they connect Thomas Hughes's representation of society as a 'seamless web of sociotechnical constructions' and the relational perspective developed in actor-network theory.

This relational perspective on (urban) space was reformulated and expanded upon in subsequent work on 'an actor-network theory of design' (Yaneva, 2009) of the built environment and on 'urban assemblages' (Farias and Bender, 2012; Farias, 2011; see also McFarlane, 2011, for a discussion of 'what assemblage thinking might offer critical urbanism'), which helped conceptualise causality in non-linear terms hence apprehending infrastructures as a result of multifarious, incremental, contingent and sometimes somewhat contradictory historical processes, and suggested an understanding of agency through a focus on socio-material relations. As Farias (2011) has it, assemblage theory aims 'to move away from a notion of the city as a whole to a notion of the city as multiplicity, from the study of "the" urban environment to the study of multiple urban assemblages' (p. 369). Applied to infrastructure, this entails an under-

²¹ In French: 'l'urbanisme des réseaux'. Dupuy evocatively foregrounds the contributions of three architects and planners 'who all adopted a global approach regarding networks' (Dupuy, 1991, p. 82): Cerdà (1867), Wright (1932, 1943) and Rouge (1953).

²² Earlier authors had sought to explore the relations between the development of telecommunications technologies and changes in the organisation of (urban) space; see, e.g., part III ('The telephone and the city') in Pool (1977), with contributions by Jean Gottmann and Ron Abler.

standing of it as a lively and ontologically unfinished repository of various socio-material features.

This changing conceptualisation of space has profound implications for urban studies beyond urban infrastructure research (see Box 1.3).

BOX 1.3 THE ONTOLOGY OF THE URBAN AFTER THE RELATIONAL TURN

The implications of this re-conceptualisation of the urban as relational are profound, both in terms of the ontology of the urban (what is it?) and its analytical value (what is the interest of doing research on cities/the urban?). Françoise Choay has, early on and with her characteristic flamboyant style, evoked it²³ in an article in French entitled ‘the reign of the urban and the death of the city’ (Choay, 1994). In this piece, she characterises the contemporary period by the domination of – especially transport and telecommunications – technological networks, resulting in ‘the undoing of the ancient solidarity’ (p. 33) between *urbs* (the city’s physical space) and *civitas* (the community of citizens inhabiting that space) (pp. 26–27). This results in ‘universal urbanization in scattered and splintered forms’ (p. 32).²⁴

Choay’s argument echoes Dematteis’s thesis of a planetary metropolitan system (Dematteis, 1988) and precedes the research by Beaverstock and colleagues (2000) on world cities within ‘spaces of flows’ (Castells, 1996),²⁵ as well as the more recent work by Brenner, Schmid and colleagues on planetary urbanisation (Brenner, 2014) and, in particular, Schmid’s understanding of urban space ‘by means of the networks that run through it and determine it’ (Schmid, 2014, p. 76). Schmid characterises how networks are ‘distributed in space’ along three dimensions: extension, intensity and heterogeneity, which remarkably echoes the ‘urban trinity’ of the Chicago school: size, density, and diversity – albeit applied to connections (or connection potentials) instead of populations (see also Pflieger and Rozenblat, 2010).

These various works underline the interest of thinking (about) the urban beyond city boundaries, through attention paid to all the interconnections and (material and sociopolitical) interdependences that ‘make cities work’ (Medd and Marvin, 2005; Cousins and Newell, 2015; Monstadt and Coutard, 2019). This echoes discussions on the relevant spatial scale(s) to decrypt infrastructure processes, which can also be connected to nation-state building (like in de Swaan, 1988; Swyngedouw, 1999; Barnes, 2017) or to regional development (Addie et al., 2020).

Yet, in spite of this relational epistemology of space that should have enlarged the scale and spectrum of analysis of infrastructures, much research on infrastructures and cities focused on infrastructures *in* cities. Illustratively, in their discussion of urban political ecology

²³ Echoing Webber’s (1967) reflections on the ‘non-place urban realm’.

²⁴ In a similar vein, see Williams (1993).

²⁵ ‘World cities are produced and reproduced by what flows through them (information, knowledge, money and cultural practices, for example), rather than what is fixed within them (i.e. their forms and functions)’ (Beaverstock et al., 2000, p. 47). See also the research carried out at GaWC: www.lboro.ac.uk/microsites/geography/gawc/index.html.

(UPE) approaches, Angelo and Wachsmuth (2015) note that:

there was another goal in early UPE programmatic statements that has largely fallen by the wayside: to mobilize a Lefebvrian theoretical framework to trouble traditional distinctions between urban/rural and society/nature by exploring urbanization as a global process. Instead of following this potentially fruitful path, UPE has become bogged down in ‘methodological cityism’ – an overwhelming analytical and empirical focus on the traditional city to the exclusion of other aspects of contemporary urbanization processes. (p. 16)

In line with the critique raised by Angelo and Wachsmuth, we consider for the purpose of this *Handbook* (and more generally) that a relational understanding of urban dynamics entails a focus on the interactions within and between infrastructure systems, spaces and organisations, and therefore on the generally multiscalar ecologies generated by these interactions. If we consider the idea of a relational understanding of the urban seriously, we must also acknowledge its inherently selective spatial nature, with places being connected to one another through variegated modalities and intensities. The ideal of the networked city, in a way, erased this spatial selectivity through the notion of (spatially and, especially, socially) universal connection to technological networks and universal access to the services they provide. The networked city ideal hence reconciled a relational understanding of space with a traditional view of space as an ‘external container’ of social life, and cities ‘as special portions of this space, bounded, enclosed’ (Graham and Marvin, 1996, pp. 54–55). This ‘best of both worlds’ view was weakened as the ideal of the networked city was increasingly questioned.

Beyond the ‘Modern Infrastructural Ideal’ and Infrastructures as Networked Technological Constructs

As the contexts in which growing numbers of urban infrastructure scholars carried out their studies diversified, so did research questions, methodologies and perspectives. Early on, the application of Western infrastructural development narratives or models to cities in other world regions were critically discussed and questioned in territorial planning studies in post-colonial contexts (see Sachs, 1977; Coing, 1980; Olivier de Sardan, 1995). This critical vein sustained a twofold movement, both analytical and normative, in infrastructure studies. First, a close attention to urban infrastructure configurations in various contexts led to the contestation of the ‘modern infrastructural ideal’ perspective according to which infrastructure could or even should be regarded as a synonym for technological network. Second, studies of ‘infrastructural lives’ led to novel conceptualisations of people as an element of infrastructure – and at times even to think of social interdependence networks as a form of infrastructure – in place of the more traditional notions of infrastructures as ‘off-the-shelf’ practical tools for (individual or collective) human action.

Shifting urban infrastructure narratives

The critique of public discourses and policies based on such generic notions as the ‘modern infrastructural ideal’ and its promise of universal access to networked basic services echoes a broader debate on the (in)ability of experts (and concepts) ‘travelling’ from one project to the next to apprehend specific contexts and the associated social logics and practical norms (Olivier de Sardan, 2021). As a result, the ‘rise of the networked city’ narrative was challenged

in many world regions, as it was contested by the reality of what Guma called ‘the spatially transient nature of infrastructure, its non-linear development’ (2022). Furthermore, as Coing (1980) remarked long ago, many cities were never fully networked and, even more importantly, were never meant to be.

Debates especially developed following the publication of the very influential *Splintering Urbanism* (Graham and Marvin, 2001) and were quite active in development studies. Sylvy Jaglin (2005), based on an extensive analysis of water services in sub-Saharan African cities and a thorough critique of the splintering urbanism thesis,²⁶ expanded the notion of infrastructure, beyond its then established understanding as a centrally managed technological network, to designate any sociotechnical delivery configuration (as per the phrase later coined by Olivier de Sardan, 2010). Subsequently, Jaglin has further documented heterogeneous configurations of supply, showing the variety of forms and assemblages that could allow the delivery of basic services (Jaglin, 2014, 2016) and its implications for urbanism (Jaglin et al., 2024).

Other ‘empirical testings’ of the splintering urbanism thesis in Global North (Moss, 2008) or Global South contexts (Kooy and Bakker, 2008; Zérah, 2008; Silver, 2014; Furlong, 2014), as well as comparative approaches across North and South (Coutard, 2008a), allowed to nuance the idea that urban socio-spatial inequalities resulted from ‘splintered’ infrastructural provision. Rather, these studies suggest, disparities in infrastructural development and access reflect broader patterns of socio-economic and socio-spatial inequalities – which more recent scholarship has complemented with a novel attention to historicised processes of redlining and other modalities of ‘racialisation of infrastructures’ (Yarbrough, 2021;²⁷ Inwood, 2023). Coutard (2008b) further remarks that ‘we can question whether it is always the case, as the splintering urbanism thesis implies, that increased service differentiation aggravates socio-spatial discrimination’ (p. 1818), thus questioning one of the key tenets of the modern infrastructural (network) ideal (see also Lawhon et al., 2018, 2023). On a broader level, the debates initiated by the publication of *Splintering Urbanism* have led to profound transformations in infrastructure studies (as reflected in Wiig et al., 2022).

Living with(out) networked infrastructures

Answering questions on the social significance of infrastructures invites to explore how they affect people’s lives: not just whether people are provided with formal access to infrastructure services, but how they use such services in their daily activities or how they manage without them. Yet, for a long time, few studies of ‘contemporary urban lives as everyday infrastructural experience’ (Graham and McFarlane, 2014, p. 1) were available, and studies focusing on ‘when old technologies were new’ (Marvin, 1988)²⁸ did not make up for this deficit. In other words, few early studies examined infrastructures ‘that are subject to widespread use’, to paraphrase Edgerton (1998, p. 816; see also Edgerton, 2011), even though there were exceptions. In France, for example, some issues of the journal *Culture technique* (n° 17, 1987; n° 24, 1992)

²⁶ Rejecting the thesis while retaining the analytical framework (on this distinction, see also Coutard, 2008b, pp. 1819–1820).

²⁷ Drawing on the case of Dallas and its highway systems, Yarbrough specifically insists on the links and entanglements between the displacement of racialised residents, predatory zoning practices and infrastructure development policies.

²⁸ For other remarkable historical studies of the early appropriation of networked infrastructures and associated technologies in the United States, see Nye (1990), Fischer (1992) and Kline (2000).

and some of the work of Alain Gras and colleagues at Cetcopra (Gras, 1997; see also Gras et al., 1992) have applied an ‘ethnographic sensibility’ (Star, 1999, p. 383) to studies of infrastructure. Yet there was little influence of these contributions in ‘mainstream’ infrastructure studies until at least the 2000s. It was only around the turn of the century that things started to change, and that empirical studies of ‘infrastructural lives’ began to accumulate.

Novel perspectives came in particular from scholars studying life with (or without) infrastructures in urban contexts where infrastructures were available only to a minority of the population, or had been de-universalised, or were failing on a regular basis – the everyday life of ordinary urban dwellers in Global South cities (Simone, 2004; Larkin, 2008; Anand, 2011; Graham and McFarlane, 2014). Through a focus on the everyday mundane experience of infrastructure, these works, and specifically Simone’s influential writings (see also Simone, 2021), offer a new perspective on the relational nature of infrastructure. Specifically understood as what Simone terms ‘social infrastructures’ (Simone, 2004, p. 407), infrastructures emerge not as a thing but as a social experience and a complex process reproducing itself continuously (see also Rao, 2014).

Infrastructures In, As and Through Practices

The focus on infrastructural lives resonates with a body of work in sociology and ethnography centred on work activities with or within infrastructures, which thus also explores infrastructural practices and infrastructural relations (albeit with a different perspective pertaining to the study of organisational change). The ‘ethnography of infrastructure’ (Star, 1999) emerged in the late 1980s and early 1990s from research on the material dimension of ‘knowledge work’ in scientific research and other activities conducted in particular by Geoffrey Bowker, Susan Leigh Star and colleagues,²⁹ and on information infrastructure, increasingly coinciding with the ‘embedded, networked, global, all-media infrastructure’ allowed by digital convergence (Edwards, 1998b, p. 99).³⁰

This scholarship significantly expanded (on) conventional understandings of infrastructures, infrastructural development and associated social phenomena, especially organisational change, by apprehending infrastructures in, as and through practices. Star and Ruhleder (1996) thus write: ‘Infrastructure is a fundamentally relational concept. It becomes infrastructure in relation to organised practices’ (p. 113).³¹ Reflecting on the ‘dual, paradoxical nature’ of technology in relation to organisational transformation, ‘both engine and barrier for change; both customizable and rigid; both inside and outside organisational practices’ (pp. 111–122), they emphasise that ‘loose talk’ about infrastructure as ‘fairly transparent for most people we know about’:

²⁹ For early contributions, see Bowker (1994), Bowker and Star (1994), Bowker, Timmermans and Star (1996) and Star and Ruhleder (1996).

³⁰ On this research stream, see also Edwards (1998a), Edwards et al. (2009), Edwards et al. (2013) and Kornberger et al. (2019).

³¹ In elaborating on this idea, Star and Ruhleder refer to the work of ‘activity theory’ scholar Yrjö Engeström: ‘Engeström, in his “When is a tool?” (1990) answers [that] a tool is not just a thing with pre-given attributes frozen in time – but a thing becomes a tool in practice, for someone, when connected to some particular activity’. Likewise, Star and Ruhleder argue, infrastructure ‘becomes infrastructure in relation to organized practices. ... Thus we ask *when* – not *what* – is an infrastructure?’ (Star and Ruhleder, 1996, pp. 112–113; see Sigaut (1991) for a similar insight to Engeström’s).

is perfectly adequate for most everyday usage but dangerous when applied to the design of powerful infrastructural tools on a wide scale. ... Most importantly, such talk may obscure the ambiguous nature of tools and technologies for different groups, leading to de facto standardization of a single, powerful group's agenda. (ibid., pp. 113–114)³²

This conception of technology as 'solidified social processes' (Beltrame and Peerbaye, 2018, p. 179) helps highlight why 'one person's standard is in fact another's chaos' (Star and Ruhleder, 1996, p. 112) and invites to shift the focus of enquiry onto the tension inherent to (all) technology. Hence, they note, 'an infrastructure occurs when the tension between local [practices] and global [standards] is resolved' (p. 114). Understanding the processes at play requires what Bowker (1994) calls an 'infrastructural inversion', i.e., the foregrounding of 'changes in infrastructural relations'³³ in studies of the development of large scale technological infrastructure' (p. 113).

Researchers within this line of research progressively extended their study objects to the mundane practices of everyday life and other dimensions of social life (for an early contribution, see Edwards, 2003). Studies have addressed in particular the consequences of the development of 'information', 'knowledge' or even 'thinking' infrastructures (Edwards et al., 2009, 2013; Kornberger et al., 2019). Researchers have explored changing consumption practices, changing patterns of social interaction ('infrastructuring sociality') (Alaimo and Kallinikos, 2019)³⁴ and broader 'infrastructuring' processes³⁵ (Edwards, 2019) associated with the unprecedented potentialities of algorithms/code in 'valuing, tracing and governing' (Bowker et al., 2019). In doing so, this scholarship provides an important contribution to the study of the 'structuring power' of infrastructures (Jarrige et al., 2018, pp. 10–11).

Dialogue between this scholarship and urban infrastructure studies has thus far been limited.³⁶ It is slowly changing under the influence, in particular, of a growing concern for infrastructure systems in STS-inspired 'maintenance studies' (Denis and Pontille, 2015; Barnes, 2017; Baptista, 2019; Denis and Florentin, 2024). Indeed, a relational approach helps conceptualise infrastructures as always in the making, never achieved; and an ethnographic approach to infrastructure maintenance proves well adapted to foreground the invisible work of 'maintainers', in a specific form of infrastructural inversion. More generally, this perspective ultimately challenges the dominant view of mature infrastructures as stable and invisible constructs and emphasises the normality of change and visibility (see, e.g., Furlong, 2011).

³² Larkin (2013) extends this argument on the meaning of infrastructures to the 'multiple level' on which infrastructures 'operate concurrently' in his discussion on the 'doubling of infrastructure' (pp. 334–336).

³³ Bowker (1994) broadly defines 'infrastructural change' as 'operations on social and natural space and time' (p. 245) mediated by 'infrastructural technologies' (p. 240) and, similarly, 'infrastructural work' as work consisting in 'organizing time and space' (p. 240).

³⁴ Continuing a long research tradition on sociability in the digital age (and before). See, e.g., Cardon and Smoreda (2014) for a survey of French research from the 1980s, based on a review of works published in the French journal *Réseaux* on 'the mutations of sociability' as 'relational technologies' multiply.

³⁵ In explicit reference to Giddens's notion of structuration. On infrastructuring, see also Coutard and Shove, 2024.

³⁶ Even though, within other theoretical frameworks, some scholars explore how the ubiquitous spread of digital infrastructures, technologies and applications affects the experience of urban dwellers (e.g., Picon, 2015; Mattern, 2021).

Likewise, there are interesting echoes between this scholarship and recent research on ‘infrastructures in practice’ (Shove and Trentmann, 2018; Watson and Shove, 2022) developed within a practice theory perspective (Coutard and Shove, 2024). These works offer complementary perspectives on infrastructuring processes, even though Bowker, Star and colleagues are mainly looking at work practices while Shove, Watson and colleagues are more concerned with the practices of everyday life.

A Belated Environmentalisation?

Considering the major influence of infrastructural development in the seemingly irresistible ascent of a ‘second nature’³⁷ over the last two centuries or so, it is remarkable that the relations between human societies and nature have long been little addressed within infrastructure studies. Admittedly, many environmental studies were carried in what are de facto infrastructure domains.³⁸ Yet most studies remained sector-specific and did not seek either to extend their approaches or insights to several such domains, or to reflect on the environmental dimension of the far-ranging and cross-sector infrastructuring processes initiated in the mid-nineteenth century.

This disregard echoes broader observations on the lack of historical studies of the relations between technology and the environment ‘in a sustained way’ until the 1990s in the words of Stine and Tarr (1998), who further note, writing about the United States, that ‘for many years, the history of technology focused on technological “progress,” while paying scant attention to technology’s consequences. Initial challenges to this orthodoxy introduced considerations typically associated with the new social history; the inclusion of environmental factors is simply an extension of this trend. Environmental history too, has only recently begun to branch out’ (Stine and Tarr, 1998, pp. 638–639). Likewise, as MacKenzie and Wajcman’s (1999) influential reader evidences, social studies of technology have examined ‘the intertwining of “society” and “technology”’ (p. xiv) but have lastingly ignored, by and large, the relations of such sociotechnical entities with the biosphere, so much so that the terms resource, environment, metabolism and even nature do not feature in the book’s index or chapter subjects. Another significant example is the nearly complete absence of environmental considerations in *Splintering Urbanism: a brief discussion of ‘the environmental movement’, evoked as ‘the third social movement which powerfully undermined the modern infrastructural ideal’, especially through ‘critiques of “big” technology’ (Graham and Marvin, 2001, pp. 133–134) and a call to ‘resist ... environmental determinism’ (p. 415). ‘(Urban) environment’, ‘(urban) ecology’ or ‘(urban) metabolism’ do not appear as entries in the book’s index either. As Blok et al. (2016) note, ‘research on infrastructure has tended to bypass the environmental problematic’ (p. 7). Reciprocally, there is little reference to infrastructures in, e.g., the ‘manifesto’ edited volume on UPE (Heynen et al., 2006). And the terms ‘(urban) infrastructure(s)’ and*

³⁷ As coined by William Cronon (1991).

³⁸ Important scholarship on the environmental implications of infrastructural development has developed around specific objects like dams (Reisner, 1993; Baviskar, 1995; White, 1996) and events such as floodings (Dawson et al., 2008; Adelekan, 2010) in an often loose connection with some urban developments. More recent works in toxic geographies (Davies, 2022) have also contributed to reconsider the role and relationship of infrastructures and their environments (see the section entitled ‘Infrastructural Violence on Spaces, Societies and Bodies’, p. 27).

‘(urban) (technological) network(s)’ do not appear as index entries in the recently published handbook on cities and the environment (Archer and Bezdecy, 2016).

There have been sector-specific historical studies (pertaining in particular to water supply and wastewater management, waste management, or transport) concerned with specific environmental issues (especially, air, water and land pollution), as well as urban environmental histories concerned with technological developments (see, e.g., Melosi, 1980, 1981, 2000; Guillerme, 1983; Tarr, 1984b; Barraqué, 1992; Bernhardt and Massard-Guilbaud, 2002; Barles, 2005). But urban environmental history as a unified domain and the specific role of infrastructure(s) – conceptualised as a cross-sector phenomenon – in the changing relations between (urban) societies and the biosphere was not explicitly explored until the early 1990s (Schott, 2004). This neglect for environmental issues broadly construed was even more marked in contemporary urban/infrastructure studies until the 2000s (Monstadt, 2009; Coutard, 2010).

The situation then gradually evolved. Often based on studies of water for or in cities (Barraqué, 2003), authors with a UPE sensibility have put forward notions of ‘cities as socio-natural hybrids’ and ‘cyborg urbanization’ (Swyngedouw, 1996; Kaika and Swyngedouw, 2000; Gandy, 2004; Karvonen, 2011). Kaika and Swyngedouw (2000), for example, using water as an emblematic example, discuss ‘technological networks [as] the material mediators between nature and the city [that] carry the flow and the process of transformation of one into the other’ (p. 120). Gandy (2004) uses an infrastructure perspective to promote ‘relational or hybridized conceptions of urban metabolism [that] are quite different from non-dialectical models of urban metabolism rooted in a homeostatic conception of the city as a self-regulatory system’ (p. 374).

This ‘environmental turn’ in infrastructure studies consolidated from the 2000s onwards, in relation to debates on sustainable (urban) development (Monstadt, 2009), climate change (Bulkeley et al., 2011; Bulkeley and Castán Broto, 2013; Bulkeley et al., 2014; Jarrige et al., 2018), and environmental challenges related to planetary boundaries more broadly. In a similar vein, some works have even insisted on the ways through which modern infrastructures have suppressed the biophysical landscape (Bélanger, 2009). In a fairly emphatic way, Pierre Bélanger thus explains the necessity to pay a closer attention to the articulation between the biosphere and infrastructures:

Food production and energy networks can no longer be engineered without considering the cascade of waste streams and the cycling of raw material inputs. Landfills, land farms, laydown and storage areas, and sorting facilities can no longer be designed without their wastesheds. Highway networks, sewage systems, and subdivisions can no longer be planned without their watersheds. Put simply, the urban-regional landscape should be conceived as infrastructure. (Bélanger, 2009, p. 91)

Consequently, growing importance is given to the contribution of infrastructures to the material and ecological footprint of industrialised and urbanised societies (Barles, 2015; Augiseau and Barles, 2017; Magalhães, 2022), and quantitative approaches on fluxes and resources increasingly overlap with infrastructure studies, through attention paid, e.g., to the articulation of technopolitics and technomass (Inostroza, 2014) or to the potential of circularity of urban or industrial symbioses (Lorrain et al., 2018; Bahers et al., 2020). This shift is highly intertwined with a critical exploration of ever more intense integration and interconnection of infrastructures (Monstadt and Coutard, 2019), which, *inter alia*, renders them (and the associated ecosystems) far more vulnerable (Graham and Thrift, 2007).

The recent acknowledgement of the crucial character of these environmental pressures – within approaches truly attentive to the materiality of infrastructures – is integral to a critique of modernity and, through this, of what Fanny Lopez (2019) synthetically called ‘LTS urbanism’. This critique of the thermo-industrial form of modernity relates to the idea that infrastructures are often the instruments and the crystallised form of unequal ecological exchange (Horborg, 2009; Hutton, 2020). Recognising this opens the way to novel conceptualisations of the interaction between infrastructures and scales of solidarity, making room for the valuation of alternative, smaller-scale infrastructure even in areas where centralised network infrastructures are generally available (Lopez et al., 2019; see Disco and Kranakis, 2013, for an alternative perspective focused on transnational, ‘cosmopolitan commons’). It also involves a renewed characterisation of the relationship between people and energy and between people and matter. Thus, the historical process of an ever-greater distancing between urbanites and matter (water, wastewater, waste) that was characteristic of the infrastructure-laden sanitary city described by Melosi (2000) coexists with a more recent trend of gradual ‘reconnection’ to matter in infrastructuralised systems – as in some ‘decentralised’ infrastructure projects for instance (Barles and Thébault, 2018; Lehec, 2019).

This novel attention to the situated relations between living (human or non-human) and non-living elements echoes, and indeed is in part directly inspired by, the development of ecofeminist theories (see Haraway, 1990; Tronto, 1993; Tsing, 2015). Infrastructures can thereby be apprehended as kin to care for, or hybrid elements to ‘think with’ and ‘for whom to speak’, to use Tronto’s words, opening stimulating research avenues.

ONGOING DEBATES

A preliminary survey of the recent literature and intense discussions at the two authors’ workshops led us to highlight four themes³⁹ relevant to contemporary (urban) infrastructural development:

- value(s) and valuation of infrastructures;
- the many faces of contemporary *infrastructuration*;
- infrastructural violence on spaces, societies and bodies and infrastructural citizenship;
- the *infrastructurocene* and its discontents.

Cutting across these four themes, a concluding essay (Addie, 2024) explores the times and temporalities of infrastructures.

In this section, we introduce each theme in turn. Taken together, they provide the structure of the rest of the book and we briefly discuss how each chapter speaks to the four themes.

Value(s) and Valuation of Infrastructures

Over the last couple of decades, an important scholarship in UPE and history of technology has revolved around processes of commodification, corporate appropriation (esp. platformisation) of infrastructures and related services. This has led to burgeoning and stimulating analyses on

³⁹ Among which, admittedly, two neologisms; but heuristic ones!

infrastructure governance models (Swyngedouw, 2000, 2015), institutional change (Lawhon and Murphy 2012) or ownership issues (Jacobson and Tarr, 1995; Moss et al., 2014) and demonstrated a general trend towards the financialisation of infrastructures (O'Brien and Pike, 2017; Furlong, 2020a) if not of natural resources (Boudia and Pestre, 2016). These evolutions are sometimes observed in a fairly acritical way (van Oijstaeijen et al., 2020; Fujiwara et al., 2022). Even though most of these works do not explicitly refer to the word valuation, they all rely on valuation issues or practices, conceived here in the tradition of critical accounting studies (and in a pragmatism-inspired way)⁴⁰ as the kaleidoscopic ways through which infrastructures matter, in monetary and non-monetary terms, and become a matter of concern (Vatin, 2013;⁴¹ Feger and Mermet, 2017).

Although rich, this scholarship captures only specific forms of valuation of infrastructures, namely those intertwined with economic or financial valorisation practices. A renewed way of attending to the differentiated forms of infrastructure ownership and management lies in recognising the coexistence of multiple forms of valuation and shifts the attention to the modalities of existence and enactment of these various valuations.

Conceptualising infrastructures through their valuation (considered here as a social practice, following Helgesson and Muniesa, 2013) thus leads to a threefold analytical change in the study of infrastructures' constant transformations:

- valuation of infrastructures is a heuristic lens to account for the role of infrastructures in urban changes (*how* does it matter?);
- it re-problematizes the issue of ownership by adding the question of responsibility (*for whom* does it matter?);
- it questions the role and importance of the different facets of infrastructure management and, consequently, possibly redirects the attention to the mundane activities and interventions that make infrastructures hold and last, reassembling thereby what counts in infrastructure management (*what* does actually matter?)

First, this then entails that valuation practices, in their different forms including financialised ones, are practices of reordering (Helgesson and Muniesa, 2013) and consequently manifest how infrastructures contribute to both institutional transformations and urban changes. They are determinants of what Philip Ashton (Ashton, 2024), in Chapter 2, calls an 'infrastructural capacity'; that is the devices, instruments and practices developed by the fiscal state to centralise resources and reorder flows of goods, people and information. The valuation practices at play here involve, in particular, the various instruments adopted by public administrations to both finance the construction and maintenance of infrastructures and to organise the appropriation of its potential revenue by various stakeholders. It puts to the fore what Ashton calls 'apparatuses of capture and control', which allows to describe both Keynesian infrastructural

⁴⁰ Following Dewey's idea of the twofold meaning of valuation: 'in ordinary speech the words "valuing" and "valuation" are verbally employed to designate both prizing, in the sense of holding precious, dear (and various other nearly equivalent activities, like honouring, regarding highly) and appraising in the sense of putting a value upon, assigning value to' (Dewey, 1939, p. 5).

⁴¹ As Vatin put it: 'valuation studies are about studying everyday inquiries about what is desired, cared about, or held precious – inquiries through which, according to John Dewey, people go from immediate valuations to more reflexive ones (asking themselves "Is it really worth it?")' (Vatin, 2013, p. 32).

developments and their more recent financialised forms,⁴² displaying two facets if not two versions of valuation of infrastructures. In a way, this epitomises Mitchell's (2011) understanding of capitalisation as a control of territory (through its infrastructures) rather than a mere calculation of a financial value (for early work on infrastructure financialisation, see Torrance, 2008; O'Neill, 2010).

In this perspective, attention to valuation processes of infrastructures is an open door into the often frictional transformations of the state, be it local or national. It allows to consider the various forms of arrangements towards large-scale political projects, such as 'energy transition' or 'smart city' projects, as variegated configurations in which infrastructures are given a different role and value, and through which the state is reordered. Various roles and values attributed to infrastructures can coexist, even within the state, mirroring political gestures that can be 'as unsettled as the technologies' they are resting on (Blok et al., 2016, p. 104). In this vein, Costanza Concetti (Concetti, 2024) explains in Chapter 3 how an infrastructural device, such as a decentralised system of renewable energy production, can radically change both the functioning of the infrastructural system (in her case, the energy one) and the forms of intervention and control of public authorities, leading, in Deleuzian terms, to processes of de- and reterritorialisation. The new device appears as a determinant and a driver of a new institutional order, which reflects conflicting forms of infrastructure valuations. In other words, through concomitant movements of internal homogenisation of local energyscapes and heterogenisation of national ones, these new infrastructures not only destabilise the current functioning of energy systems but produce new forms of stateness, and offers opportunities for the development of new governance schemes, in line with calls for 'energy democracy' 'in-against-and-beyond-the-State' (Angel, 2017). At a more local level, expanding on work on the governance of smart city projects (e.g., Kitchin, 2014), Julia Valeska Schröder, Claudia Mendes and Ignacio Farías (Schröder et al., 2024) explore in Chapter 4 another type of state reordering (actually city reordering) through infrastructure, namely what they call 'smart city new deals'. Such new digital projects are analysed not only as optimisers of flows within the city but also as important agents of administrative internal transformations. Following works on the coproduction of infrastructures *à la* Jasanoff (2004), they show how administrative reforms and the implementation of digital infrastructures are neatly entangled and coproduced in what they describe as a 'recursive' way through which local administrations are actively transforming themselves as they integrate digital infrastructures. Through these 'smart city new deals', a renewed form of valuation is performed, whose final outcome is not restricted to the fluidification of flows but enlarged to the transformation of the local state itself.

Second, attending to the processes and practices of valuation of infrastructures transforms and re-problematizes – and possibly collectivises – the question of infrastructure ownership. Indeed, if we admit the possibility of coexistence of various forms of valuation of infrastructures, the actual forms of infrastructure ownership can then differ from their traditional legal status. A valuation approach encompasses the various processes of attachment to infrastructures, understood here as both a form of appreciation of the infrastructure and the recognition of an interdependence with this infrastructure through the services they provide (on attach-

⁴² These have recently been analysed in articulation with the scholarship on the racialisation of infrastructures in stimulating works like those by Sage Ponder, who analysed the deteriorated access of Black-majority US cities to bond markets and financing schemes for urban infrastructures (Ponder, 2021).

ment, see Hennion, 2004, and specifically on infrastructures, see Monnin, 2021). It makes ownership not only a matter of possession, but also of responsibility for all infrastructure stakeholders, including their users. As Moss, Becker and Naumann have argued concerning the infrastructures of the German energy transition, ‘Current debates on ownership are shifting from a simple “private vs. state ownership” dichotomy to accommodate more differentiated and collective forms of ownership’ (Moss et al., 2014, p. 1549). One such shift opens new possibilities for considering infrastructures as commons or as agents of commoning processes.

While the long phase of infrastructure fragmentation experienced in various contexts has been largely documented, the question of its reconfiguration and the possibilities of re-aggregation of these systems under the umbrella of infrastructural commons remains open. In a stimulating reflection, the cultural theorist Lauren Berlant (2016) suggested to apprehend the commons as infrastructures of sociality for ‘troubling troubled times’ (p. 395), recognising at the same time that the commons concept can be considered ‘a way of positivizing the ambivalence that saturates social life about the irregular conditions of fairness’ (p. 395). Berlant’s argument suggests that, reciprocally so to speak, the commoning of infrastructures can be seen both as a political project and as a methodology to address issues of social and material justice (as illustrated in one of the Italian cases studied by Concetti in Chapter 3). From the perspective of this *Handbook*, her use of the notion of infrastructure is fairly metaphorical, yet her political take at the notion of commons – as a space of productive expression of the ‘commonality of difference’ (p. 399) – is fully relevant.

As often stated, the growing literature on commons and its infrastructural declensions epitomises the topicality of the theme as well as its ambivalent use and sometimes loose relationship with Ostrom’s work (Metzger, 2015). De Gouvello and Jaglin’s (2021) portrayal of the articulation between infrastructured services and the commons vividly illustrates these ambivalences, spanning between: social practices of commoning that claim for some emancipatory reappropriation of goods and infrastructures (Dardot and Laval, 2014); interstitial forms of collective reappropriation of public goods in the ordinary urban world (Hardt and Negri, 2017; Rossi, 2019); hybridised models of properties including some cases of commodification (Le Roy, 2016); and the quest for a juridical category defining the roles and responsibilities over time of ‘commoners’ (Gutwirth and Stengers, 2016). Following these various paths, initiatives enacting a form of infrastructural commoning, i.e. the collective reappropriation of infrastructures, have been burgeoning over the last couple of decades, taking variegated forms such as energy communities, water cooperatives or community clouds (Baig et al., 2015). In their text, Alexander Paulsson and Jens Alm (Paulsson and Alm, 2024) give a good illustration of the ambivalences of infrastructural commoning through one specific object, civic roads, the legacy of a centennial practice of devolution of road management to citizens and somewhat an imposed common (Chapter 5). Their analyses of this Swedish infrastructure trace the challenges faced by those accountable for the orderly functioning and maintenance of civic roads. On the one hand, the financial burden plays a predominant role in the difficulties to sustain these commons, almost tearing down the collective arrangements on which they are resting; yet, on the other, this collective ownership and its additional moral and fiscal responsibility make the infrastructure matter when degradation occurs and create new forms of commoning around the necessity to fairly allocate the costs of repair of these infrastructures.

Third, being attentive to valuations of infrastructures connects valuation with accounting in its etymological sense, i.e. making count what really counts and matters. Analytically, this coalesces with the idea of re-embedding monetary considerations within social and

material dynamics, in a classic Polanyian way, and has major methodological and epistemological implications for the understanding of infrastructural and urban transformations. Methodologically, such a focus entails the necessity to pay close attention to often invisibilised yet essential facets of infrastructure management, such as maintenance practices (Denis and Pontille, 2015, 2022; Henke and Sims, 2020) and all the interventions aimed at upkeeping infrastructures (Denis and Florentin, 2022) and as such calls for ethnographic approaches aimed at grasping infrastructures in or through their mundane routines. Epistemologically, this contributes to reposition the attention of infrastructure studies on existing systems (and not on projected ones), on their constant decay (Graham and Thrift, 2007; Jackson, 2014; Mattern, 2018) and on the ways in which this continual degradation is either ignored or integrated within infrastructure management, be that in Southern contexts (Etienne, 2022) or in Northern configurations (Strebel, 2011; Strebel et al., 2019).

This resonates with the writings of Maria Puig de la Bella Casa (2011) on ‘matters of care’, which highlight the necessary articulation between actions of repair, maintenance and a form of personal engagement to make infrastructures both work and last. According to her analyses, one of the main challenges is for practices of care to become collective political issues, i.e. ‘matters of concern’. In other words, acknowledging the coexistence of different forms of valuation of infrastructures possibly leads to foregrounding and re-politicising certain infrastructural activities and, for infrastructures managers, to reshaping infrastructural strategies accordingly. In their chapter, Nacima Baron and Yassine Khelladi (Baron and Khelladi, 2024) explore the ambivalences of massive policies of infrastructure repair and maintenance (Chapter 6), epitomised by a case study of a railway network of the Paris region. They show how infrastructure management is facing increasingly unsolvable dilemmas, as it is torn between the imperative of service continuity, political pressure to maintain a high level of service performance and the important degree of infrastructure degradation that impose often incompatible forms of social, political and material constraints. This can lead up to the almost contradiction of practices of repair that are actually damaging infrastructures rather than stabilising them.

In a similar vein, Jérôme Denis and Daniel Florentin (Denis and Florentin, 2024) analyse practices developed by managers of infrastructure systems (namely, water networks) to deal with existing assets and their degradation due to ageing processes (Chapter 7). Putting the focus on infrastructural maturity transforms the ways in which infrastructures are counted and valued and places the question of infrastructure maintenance at the centre of operational agendas. Considering such an ‘age of maintenance’ thus entails reconsidering how infrastructures come to matter, in the various declensions of the word.

The Many Facets of Contemporary Infrastructuration

Various approaches have been used to explore the social significance of infrastructural development. Over the four decades or so covered in this introduction, a broad agreement was reached within historical and social studies of technology on the need to advance less deterministic, more relational and more ‘ecological’ approaches to ‘infrastructures-in-society’, and to move beyond narratives of innovation diffusion and system-building to examine the slow and always on-going processes of mutual influence between material arrangements and social practices – what Andrew Barry named ‘infrastructures in process’ (2020).

An increasingly influential stream of research has foregrounded *infrastructuring* processes (Star and colleagues) – the complex set of operations involved in the making of technical, organisational and individual arrangements into infrastructures – through what Bowker (1994) has called ‘infrastructural inversion’. Concomitantly, but largely independently, a growing number of scholars have become interested in the influence exercised on the living conditions of urban and other populations by the infrastructuring of the provision of essential everyday life services (or its absence or failure) (e.g., Karasti and Syrjänen, 2004; Furlong, 2014).

In this perspective, the notion of *infrastructuration* proves heuristic. We use this term here to point to the material dimension of the structuration process(es) as defined and described by Giddens. Although Giddens does consider some material elements shaping practices, he does not seriously address the infrastructural dimension specifically, when much of the scholarly work evoked in this introduction (and beyond) strongly suggests, on the contrary, that it is a significant dimension of structuration in modern society. As a consequence, it can also be assumed that changing infrastructural arrangements affect structuration processes. A focus on infrastructuration, broadly conceived as infrastructure-equipped or -related processes of structuration, thus appears both illuminating and timely to grasp what makes an infrastructure (Edwards, 2019; see also Coutard and Shove, 2024 for further developments on this issue).⁴³

Yet, how can one *methodologically* account for these dynamics of infrastructuration? A substantial body of research has insisted on the importance of being attentive to the modalities of a mutual shaping of infrastructures, devices and practices (see, e.g., the contributions to Shove and Trentmann, 2018). A focus on norms, habits or routines around specific objects thus helps characterise processes of infrastructuration (Star and Ruhleder, 2016; Edwards, 2017, 2019), including their moments of tensions or even failures. An example is provided by Ureta in his study of the failed infrastructuration associated with the development of the Transantiago bus system (Ureta, 2015). In a similar ‘counterfactual’ vein, Velho (2021) highlights the variegated ways in which wheelchair users challenge the assumed invisibility of (public transport) infrastructure in their everyday use of it, vividly illustrating Star’s observation that ‘one person’s infrastructure is another’s topic, or difficulty’ (1999, p. 380).

Such a perspective leads to the conceptualisation of some objects as infrastructures, underlining their transformative role on existing forms of sociality and territoriality, as developed in various contributions in the *Handbook*. Through their analysis of urban security *dispositifs*, Damien Carrière and Priyam Tripathy (Carrière and Tripathy, 2024) illustrate this process and show the various modalities of infrastructuration characterising these apparatuses of urban control (Chapter 8). They reveal how the smooth functioning of the city and its various rhythms are conditioned, allowed and performed through the development of context-specific security systems, which they consequently qualify as infrastructures. Through this, they illustrate how these security systems possess or reflect a specific infrastructural ‘disposition’, to use Keller Easterling’s terms (2014), i.e. ‘the markers of inherent agency’. In a somewhat

⁴³ In their discussion of the materiality of daily life, Coutard and Shove (2024) apprehend infrastructuration as ‘the dynamic, always in the making processes of mutual constitution of infrastructural environments and of the ordinary practices of daily life’. This practice-oriented approach echoes, though with a different methodological perspective, the law-inspired approach of infrastructure and infrastructuration, as developed by Mariana Valverde (2022), who pays attention to the ‘infrastructure-enabling field’, i.e. the complex apparatus of financial and legal arrangements (such as bonds, audits or credit ratings) that constitute the conditions of possibilities of infrastructure’s (legal) existence and reproduction.

similar vein, Ludovic Halbert offers an analogous illustration of this methodological gesture (Chapter 9). The analysis of the relationships between the evolution of the built environment and the configuration of investments circuits supporting it translates into a conceptualisation of these investments circuits as infrastructures. This allows to see, through attention to the calculation practices involved, how these circuits are embedding forms of structuration of the built environment and endow the capital they circulate with a ‘specific texture’ (Halbert, 2024).

These rather ethnographic approaches of infrastructuration through a focus on (user) practices can be completed and enriched by other methodological approaches, such as those inspired by design theory. In this regard, Leonardo Ramondetti (Ramondetti, 2024) (Chapter 10) astutely accounts for infrastructuration and (conception and use) practices through various visual methods inspired by landscape ethnography (Crang, 2009). This representational approach informs how various facets of infrastructuration find materialisation and get appropriated in urban landscapes.

The methodological challenges involved in apprehending the various facets of infrastructuration can also be read as an indicator of the fairly significant heterogeneity of infrastructural configurations (Jaglin, 2014; Lawhon et al., 2018; Guma, 2020). Recognising this heterogeneity also entails an *ontological shift*, as it questions the very modes of existence of infrastructures, extending it to user practices but also to the various labour activities that are integral to the functioning of infrastructures (Simone, 2004; Baptista and Cirolia, 2022). Liza Rose Cirolia and Andrea Pollio (Cirolia and Pollio, 2024) challenge this scholarship on infrastructural heterogeneity to go beyond its descriptive character (Chapter 11). This passes through the identification of the blind spots of hybridity and a repoliticisation thereof, notably by insisting on the frequent articulation between off-grid service delivery configurations and still dominant grid infrastructures, or by criticising the widespread conflation of hybridity and urban poverty, which often proves wrong. In a complementary perspective, Sylvie Jaglin, Mélanie Rateau and Emmanuelle Guillou (Jaglin et al., 2024) expand on the scholarship on hybrid or heterogeneous infrastructures to delineate the possible features of what they term ‘hybrid urbanism’ (Chapter 12). In doing so, they outline a new agenda aimed at producing infrastructural imaginaries that could escape from, question and relativise the hegemony of networked urbanism.⁴⁴

The ongoing infrastructuration evidenced in the previous chapters goes hand in hand with still increasing flows of material resources, a dimension long neglected by infrastructure studies (Coutard and Florentin, 2022). Olivier Coutard and Elizabeth Shove (Coutard and Shove, 2024) explore the ways in which the prevailing dynamics and patterns of infrastructuration involve specific forms of relations between practices and material resources that tend to make resource use less visible to infrastructure stakeholders (Chapter 13). Positioning the debates on infrastructuration in this perspective resonates as a call for a more resource-sensitive approach to infrastructures and for the revisibilisation and repoliticisation of the relationship between the practices of daily (urban) life and the metabolised energy and material resources associated with them.

⁴⁴ See also Lawhon et al. (2023).

Infrastructural Violence on Spaces, Societies and Bodies

Infrastructure studies have long examined the duality of the infrastructural condition that connects and disconnects, providing access to basic services to some while excluding others, and contributing thereby to a form of what some researchers have, over the last decade, started to refer to as ‘infrastructural violence’. This duality mirrors sociopolitical processes encapsulated and materialised in infrastructures, which contribute to the (re)production, and self-perpetuation of power relations and social interests (e.g., McFarlane and Rutherford, 2008; Pilo, 2017; Truscillo, 2020; Baumann and Yacobi, 2022). A number of studies have examined absent, intermittent, disrupted, or exclusionary infrastructures and their implications for urban populations (Graham, 2010; Anand et al., 2018). These works show how unequal access to infrastructures and infrastructural services is predominantly concomitant with differentiated belonging to the city (Caldeira, 2000), a sign of marginality (Anand, 2017) or incomplete material citizenship (Chatterjee, 2004; Lemanski, 2019), if not an urban stigma (Baumann and Yacobi, 2022).

Infrastructural violence cannot be viewed simply as a passive feature of socio-spatial differentiation. It is also the outcome of processes that reveal the agentic power of infrastructures in reshaping social structures and social relations (Amin, 2014). As Shamir has it while describing the politics of electricity in Palestine, ‘the purpose here is to explore how electrification “makes politics” rather than merely transmits it – how electrification participates in the formation of distinct ethno-national groups rather than simply reflecting it’ (Shamir, 2013, p. 5). This active role underlines the heuristic value of naming this form of infrastructure inequality as violence: following Joia Mukherjee and her coauthors, it stresses that violence is characterised by two elements, the presence of brutality and the notion of intent (Mukherjee et al., 2011). Yet some of the contributions to this *Handbook* question the level of such an intent. Furthermore, this violence and its entailed brutality do not necessarily take the visible form of network disconnections or breakdown. Often, what are at play are indirect, silent and often slow forms of violence (Nixon, 2011), which can ‘become unmoored from their original causes’ (Davies, 2022, p. 410), in particular when unequal access to services implies reduced life chances and possibilities of action in the city (Baumann and Yacobi, 2022).

The phrase ‘infrastructural violence’ has in particular gained salience since the early 2010s. In their introduction to a special issue of *Ethnography* precisely dedicated to that theme, Rodgers and O’Neill (2012b) note that infrastructures are at once a ‘material embodiment’, an ‘instrumental medium’ and a productive ‘site of investigation’ of violence, especially ‘structural violence’ (see for a pioneering contribution to this notion Galtung, 1969), i.e., ‘violence exerted systematically – that is, indirectly – [admittedly on people] by everyone who belongs to a certain social order’ (Farmer, 2004, p. 307, cited by Rodgers and O’Neill, 2012b, p. 404). While Rodgers and O’Neill have emphasised the entanglements between infrastructural and structural violence, this debate has been enriched by Davies who has highlighted the commonalities between structural and slow violence, contending that ‘slow violence is built on the bedrock of social inequality’ (Davies, 2022). This manifold development of research on infrastructural violence is often referred to post/colonial contexts or issues (Axel et al., 2021), but the relevance of this notion extends well beyond this particular study area, as several chapters in this volume illustrate.

On a general level, three main interrelated manifestations of infrastructural violence can be isolated, which are then developed in turn. These various manifestations can also be read as

pressures and constraints exerted on what some authors have termed ‘infrastructural citizenship’ (Lemanski, 2019).

A first research stream addresses the more or less *coercive forms of infrastructural control exerted on or through space* and its differential organisation, accessibility and use.

Inspired in part by critical research on urban planning in colonial contexts, a more radical critique is now developing, which emphasises the historical role of infrastructures as a tool for exerting power over colonised territories and native populations and its enduring role in (sustaining) structural inequalities in many contemporary cities and territories with a colonial history. A growing body of research shows how the production of infrastructures such as electricity or transport networks in (settler) colonial systems was generally based explicitly on racial discrimination (see Chikwero, 2007 for a study in the context of colonial Zimbabwe; Rao and Lourdasamy, 2010 on the case of the colonised Indian territory; or Cowen, 2020 on Canada).

Research on settler colonialism has shown that the production of colonial infrastructures implied processes of land sequestration, mobility segregation and dislocation of the indigenous economies (Jabary Salamanca and Silver, 2022). It thus points to an active link between imperial modernity and infrastructures (Kooy and Bakker, 2008; Jabary Salamanca, 2016), which is developed in the chapter by Holly Randell-Moon (Randell-Moon, 2024) (Chapter 14). She explains how the production of urban spaces and their infrastructuring rested, in several countries, on artefacts and imaginaries that were excluding if not erasing the presence and organisation of Indigenous populations, including traces of their infrastructural pasts. Infrastructural violence, in these contexts, translates into the separation of space and people, with some authors suggesting that infrastructures would be informed by ‘regimes of race’ (Jabary Salamanca and Silver, 2022). These works elaborate on the post-colonial and racial specificities of what infrastructure studies have long implicitly included in the generic idea of the reproduction of urban power and inequality issues by and through infrastructures. After Stoler (2008), who suggested to define ‘the contemporary zones of imperial duress [by] the breadth of corridors in which people can move, the virtual barriers by which they are cordoned off, the kinds of infrastructure to which they have access, and the preemptive racialized exclusions and exemptions in which they live’, recent literature foregrounds ‘the legacy of colonial infrastructure, in both its material and epistemic dimensions’ (Davies, 2021, p. 740), ‘the intersection of labour, race and finance’ at play in infrastructure development (ibid., p. 741) and ‘imperial remains ... theorized as the residues ... of racism and colonialism in the present’ (Kimari and Ernston, 2020, p. 827).

Their heuristic stems from the ability not only to capture the different forms of violence produced or mirrored by infrastructures, but also to identify the articulation between these systems of infrastructural violence, to show, in an intersectional way, how infrastructures, in their violent component, are ‘interconnected and co-constituted through each other’ (Truelove and O’Reilly, 2021).

A second stream explores *how infrastructural violence operates at the level of individuals* by focusing on the bodily or ‘intimate’ (Baumann, 2018) experience of such violence. This has been widely illustrated in emerging works on toxic geographies, which epitomise a slow form of infrastructural violence ‘hidden in the tissues of bodies’ (Armiero and Fava, 2016), linked with the deferred environmental threats caused by some infrastructures (see Davies, 2022 on the infrastructures of the cancer alley, for example).

Research in this area also partly derives from surveillance studies inspired by a Foucauldian perspective, which have been a very dynamic field since the late 1990s (Lyon et al., 2012). Work in this area has acknowledged the fact that novel forms of social control, based on the global, or systematic, monitoring of individuals' practices or speech, are developing at an unprecedented level through intensive use of various digital technologies.

Another factor accounting for the development of research on bodily experiences of infrastructural violence is the increasing ethnographic sensibility in urban infrastructure studies (Elyachar, 2010; Anand, 2011, 2012; Rodgers and O'Neill, 2012a; Baumann, 2018; Baumann and Yacobi, 2022) that has led to 'considering infrastructure as an ethnographically graspable manifestation' (Rodgers and O'Neill, 2012b, p. 401). This helped in exploring how infrastructure provision affects the living conditions of urban populations from the perspective of individuals rather than from the perspective of structural factors (alone). Kei Otsuki (Otsuki, 2024) provides an illuminating illustration of this process in her ethnographic examination of a double infrastructural violence in development-induced displacement and resettlement projects (Chapter 15). The inherent intimate brutality of displacement is bolstered by the deceits created by unfulfilled promises of modernity allegedly brought by infrastructures and leading to slow and partly unintentional forms of infrastructural violence.

The difficulties in identifying clear causes to these manifestations of slow violence raise important epistemological and methodological questions about how to concretely grasp 'how [infrastructural] violence operates' (Baumann, 2018, p. 139;⁴⁵ see also Truelove and O'Reilly, 2021). To attend to this challenge, Hanna Baumann (Baumann, 2024) offers an arts-inspired perspective (Chapter 16). The analyses of artistic performances and artworks in and about contexts of slow infrastructural violence due to toxic contaminations reveal the intimate effects – in the forms of feelings, affects or emotions – of infrastructural projects beyond the classic measure of inequality. This provides a new understanding of the relationship between urban dwellers, infrastructures and the public authorities in charge of their management.

Reciprocally, anthropologists have convincingly argued that a focus on infrastructures and how they affected the everyday lives of urbanites offered new insights on how individual experience relates to social structures, and in particular to structural violence (Galtung, 1969). Infrastructures according to this perspective are claimed to be 'the "physical and spatial arrangements" through which a society's overarching values and prejudices can be read' (Boehmer and Davies, 2018, p. 2). This largely echoes the disciplinary aspects of infrastructural projects and their manifold effects on urban practices, as developed by Sarah Turner and Binh N. Nguyen (Turner and Nguyen, 2024) (Chapter 17). These projects reflect normative visions of infrastructure uses and sanctioned forms of movements; symmetrically, they may also impede or police unsanctioned ones, creating forms of urban disorder and reinforcing in a brutal manner various forms of injustices.

A third stream examines the counterintuitive *immobility performed by infrastructures*. The scholarship on infrastructural violence has contributed to document an emerging manifestation of violence, in the wake of previous research on infrastructured surveillance (Lyon, 2001; Graham, 2010), echoing the military origin of the term infrastructure (Edwards, 2003). While infrastructures are still predominantly associated with the smooth flow of people, matter,

⁴⁵ Baumann (2018) 'argues that cultural engagements with the personal, embodied, and symbolic effects can help us understand infrastructural violence better. We find in these intimate effects an integral aspect of how this violence operates' (p. 137).

information or finance (Lindquist, 2017), mobility, infrastructure and surveillance studies in combination have shed light on the production of infrastructures aimed at separating spaces/groups or preventing movement.

This is apparent, for example, in the notion of arrival infrastructures, popularised by Meeus et al. (2019) to capture the urban *dispositifs* that are framing the trajectories of migrants, and through which forms of infrastructuration of immobility and coercion are made visible and enacted. In a somewhat similar vein, Oscar Figueroa, Carole Gurdon and Paulette Landon (Figueroa, 2024) explore the ambivalences of mobility infrastructures in their capacity to immobilise vulnerable populations (Chapter 18). In a revisited version of the splintering urbanism hypothesis, they portray the conditions of immobility of marginalised people produced by the development of specific premium infrastructures such as a toll highway.

What ties together these various manifestations of infrastructural violence is not only a common form of brutality and constraint exerted on bodies, spaces or the environment, but also a type of relationship with infrastructures and its articulation with the modalities of belonging to the city (Anand, 2011). This has been grasped by the burgeoning scholarship on *infrastructural citizenship* with their sectoral declensions such as hydraulic citizenship (Anand, 2011) or waste citizenship (Fredericks, 2018). This scholarship is largely inspired by pioneering works on material citizenship (Chatterjee, 2004) and offers a stimulating framework to analyse long-term relationships between humans, institutions and infrastructure services (Lemanski, 2019, 2020). Such relationships reveal different versions of this (often incomplete) citizenship, which are epitomised in three different chapters. Looking at streets in Southern contexts, Yogi Joseph, Sreelakshmi Ramachandran and Govind Gopakumar (Joseph et al., 2024) point to the hegemony of an automotive citizenship (Chapter 19). They insist in particular on how the (re)production of such a state-humans-technology relationship largely disregards other, de facto marginalised practices of the streets and of urban spaces more generally. In a way, this sheds light on some forms of disjunctions between infrastructure planning and infrastructure practices, which are at the core of the chapter by Lindsay Blair Howe (Howe et al., 2024), Margot Rubin, Sarah Charlton, Muhammed Suleman, Alexandra Parker and Anselmo Cani (Chapter 20). Examining infrastructure planning practices from a Southern urbanism perspective, they identify a form of what they term ‘infrastructural indifference’, understood as a very loose integration of the various publics of an infrastructure (Collier et al., 2016) and as a fairly degraded form of infrastructural citizenship. Lastly, Charlotte Lemanski (Lemanski, 2024) probes the material and political effects of heterogenous post-networked configurations on infrastructural citizenship (Chapter 21), including attention to the fiscal relationships between citizens and the local state, which result in potential tensions on expectations and practices around infrastructures.

The *Infrastructurocene* and its Discontents

The first three themes have manifested variegated forms of relations embedded in infrastructural configurations. The last theme will tackle a specific relationship, articulating infrastructures and resources, captured under the idea of an *infrastructurocene*. This ‘notion’ of *infrastructurocene*, broadly construed as a way to conceptualise resource-related and environment-based infrastructural dynamics, could be seen merely as an addition to the already long and still growing list of -ocene (and even -ucene) neologisms (after Anthropocene) encountered in the critical social science literature: Techno-anthropocene; Anthro-obsene; Capitalocene,

Plantationocene; Chthulucene; Necrocene; Alienocene... In this text, it is meant as a provocation and an invitation to reflect not only on the unquestionable, but little addressed as such, contribution of generalised infrastructuration to current global environmental changes; but also, on a different level, on the limitations of each of these neologisms insofar as it singles out the primary, or even sole, responsibility of one specific social phenomenon. Indeed, focusing on infrastructure as the driver of the Anthropocene (over the other scenes) begs the question of what drives the *infrastructurocene*.⁴⁶

Whichever causalities are at play, our current infrastructural times can be characterised by a form of resource-related crisis, which has important implications at various scales, and notably the urban one. Some figures have emerged from that concern, such as *off-gridders* (Lopez, 2014; Vannini and Taggart, 2015), who are questioning not only an end-of-pipe solutionism, but also the forms of solidarity and political organisation traditionally associated with urban networks. This form can even be radicalised through the figure of ‘preppers’, groups or individuals anticipating and preparing for some harsh and durable infrastructural dysfunction and disconnection.⁴⁷

To grasp its variations and different manifestations, we discuss below four facets of this *infrastructurocene*.

The first relates to *the complex relationship between infrastructures, data and resources*. Large-scale infrastructure systems have indeed long been framed as resource-efficient sociotechnical arrangements of service provision. Yet, their material and energy footprint and the dynamics of growth of resource-intensive practices they have often supported have largely been neglected (Coutard, 2010, and also Coutard and Shove, 2024). Responses to resource-efficiency concerns have of late tended to rely primarily on digital technologies, with a promise (Joly, 2015) that the advent of ‘smart’ infrastructures would improve resource efficiency both on the ‘supply’ and the ‘demand’ sides. This has nourished a romanticised interpretation of technological transformations, with some experts calling for a reinforcement of the digitalisation of infrastructures to reach green and carbon-neutral urbanscapes (Lorrain, 2018), while paying little attention to its political or material implications. Yet, such (potential) efficiency gains are often overstated and the energy and material consumption of digital infrastructures (the ‘cloudinfrastructures’ mentioned by Furlong, 2020b) tends to be overlooked, leading to the largely contested idea of a possible decoupling between the provision of infrastructure services and pressures on (natural) resources (Haberl et al., 2017). The tensions associated with the development of ‘green and smart infrastructures’ therefore need to be more widely studied. Along those lines, Morgan Mouton (Mouton, 2024) offers an overview of what the increasing integration of smart systems do to the management of urban fluxes (Chapter 22). He insists on the potential of ‘legibility’ allowed by the production of data on and around urban fluxes of matter and energy, hence on the potential for an improved governability of those fluxes, and on the concomitant ‘ordering’ of urban metabolism that these data infrastructures induce.

⁴⁶ We thank Kathryn Furlong for this formulation.

⁴⁷ ‘The stuff of prepping can be understood as a “shadow infrastructure,” curated to enable material autonomy in the crisis space beyond collapse’ (Barker, 2020, p. 489). Through this idea of shadow infrastructure, an entire sociopolitical and material world is suggested, which opens new directions for future research on infrastructures.

On a more general level, these large-scale infrastructures embody productivist, extractivist and resource-intensive political economic systems with which they have been associated historically since the early nineteenth century and the development of the railways (Jarrige et al., 2018; Lopez, 2019). A resource-sensitive approach to infrastructure is therefore needed to understand the direct or indirect processes through which infrastructures development has been historically supporting an unsustainable use of non-renewable resources (Coutard and Florentin, 2022). These large infrastructure systems are consequently at the centre of manifold perturbations and transformations, encompassing climate destabilisation (Chester and Allenby, 2019; Chester et al., 2020). Incumbent large infrastructures are signs and features of a thermo-industrial modernity; they embody a symbolic and material form of accumulation (of goods, wealth, but also exclusion) (Fressoz, 2020, who describes this as a characteristic of an *accumulocene*). Through their contribution to this accumulation and to the transformations of biogeochemical cycles and due to the intensification of resource metabolism they entail, they are thereby essentially anthropocenic.

The second facet of infrastructurocene articulates *infrastructures and the metabolism of natural resources*. Converging concerns for the material and carbon footprint of contemporary societies and for the depletion of natural resources in relation with global environmental changes have deeply transformed our (recent) understanding of infrastructures, putting more emphasis on the idea of changing metabolisms (Barles, 2015). These approaches demonstrate a neglect of the infrastructural ‘technomass’ (Inostroza and Zepp, 2020), i.e. the materiality of the resources involved, considered in terms of both quality and quantity. This has resulted in the relative dearth of analyses of some infrastructured materials, such as construction material, even though they constitute the second largest urban material flow (Barles, 2017; Goizauskas and Tisserand, 2024).

Considering infrastructures through these lenses helps raise issues of equity, legitimacy, sustainability and appropriation, but concerning the resources used rather than (only) the services provided (Williams et al., 2019; Elsner et al., 2019). In this respect, infrastructures are a fruitful locus to observe the interdependencies between urban areas and the fluxes that ensure their fluid or contested functioning (Monstadt and Coutard, 2019). In other words, metabolic concerns are a way to connect infrastructures, the resources they use and their relation to their living environments (Coutard and Florentin, 2022). In this perspective and through a critical reading of the scholarship on urban metabolism, Pierre Desvaux (Desvaux, 2024) offers a conceptual and methodological framework based on the notion of ‘metabolic pathway’ (Chapter 23). This notion is a middle way to overcome the tensions between purely quantitative or material-blind approaches of urban metabolism, accounting for the sociotechnical conditions that allow the metabolism of resources. This conceptual contribution is also operationalised by Jean Goizauskas and Carole-Anne Tisserand (Goizauskas and Tisserand, 2024) in their analysis of the processes of infrastructuring of excavated soils planned for urban constructions (Chapter 24). They show how metabolic pathways, in this case around urban soils, are a useful way to conceptualise the making of a resource and understand it as the complex articulation of the roles of both soils and humans, within a process of stabilisation of material practices.

A third facet of a so-called infrastructurocene has to do with *the role of infrastructures in the contemporary discourses and strategies of ‘transition’* (whether environmental, energy,

low-carbon, digital...⁴⁸ This role questions both the adaptability of fairly obdurate systems (Hommels, 2005) and the potential infrastructural vulnerabilities⁴⁹ generated by strategies of transition (Florentin, 2015). In other words, this opens debates on the extent to which these transitions are destabilising the current urban infrastructure regime, if not producing a new one (Monstadt and Wolff, 2015). José-Frédéric Deroubaix and Julie Gobert (Deroubaix and Gobert, 2024) bring a provocative contribution to these debates by demonstrating how decentralised green infrastructures, far from undermining the functioning of traditional LTS, can contribute to their persistence and even their stabilisation (Chapter 25). A ‘dynamic status quo’ emerges from the co-presence and articulation of these two systems, illustrating a form of resistance of existing sociotechnical arrangements. In a complementary perspective, Tauri Tuvikene, Wladimir Sgibnev and Carola S. Neugebauer (Tuvikene et al., 2024) offer a useful conceptual shift on the issues of infrastructural transitions thanks to the analysis of systems once universal that have then experienced major crises (Chapter 26). Through the specific context of post-socialist configurations, they put to the fore the existence of what they call a ‘system of less’, profoundly marked by resource scarcity and infrastructure dysfunctions but whose patterns can also provide lessons for new more sustainable infrastructural futures. These different approaches show how infrastructural changes are deeply intertwined with concerns for infrastructural vulnerability. Anique Hommels (Hommels, 2024) further elaborates on these issues by considering infrastructural transitions from a reverse perspective, so to speak, looking at situations of urban vulnerability or crisis and at the infrastructural ‘responses’ to these situations (Chapter 27). She particularly explores their innovative potential for infrastructural systems and calls for a deeper scrutiny of such dynamics to be attentive to the variety of infrastructural changes in times of multiple crises and augmented vulnerabilities.

A last facet of infrastructurocene consists in *an ontological questioning of the modernist-influenced relationship between infrastructures and their surrounding environment*. An understanding of the infrastructurocene not only implies a closer attention to the role of infrastructures in the transformation of our environments, but also entails methodological sidesteps, where infrastructures are considered from the perspective of the living environment in which they are enshrined, to set their relational nature in a broader, more-than-human perspective (Metzger, 2015). In that vein, as Atsuro Morita emphasised in his study of the implications of large hydraulic infrastructures on other activities in the Chao Praya delta, ‘attentiveness to the particular multispecies relations between people, rice and other things facilitates a reconsideration of infrastructure’s relationship with nature’ (Morita, 2016). Important contributions stemming from STS and from anthropology thus insist on the heuristic value of reconsidering infrastructures within and sometimes even as a living environment, which blurs the boundaries of what an infrastructure encompasses and calls for a renewed understanding of urban infrastructure ecologies. Through the example of road infrastructures maintenance, Roman Solé-Pomies (Solé-Pomies, 2024) illustrates this boundary work and the

⁴⁸ Infrastructure transitions themselves are carrying a form of ambivalence: an important body of research based on a multi-level perspective approach to sociotechnical transitions (Geels, 2004) has accounted for infrastructural change in a fairly organisational, often a-spatial and almost deterministic manner, while some historians and geographers have insisted on the complex socio-political nature of infrastructure transitions and their non-unitary territorialities (Gailing and Röhring, 2016; Bridge, 2018).

⁴⁹ Understood here as the vulnerabilisation and weakening of the different components of infrastructures: its technical functionalities, its economic viability, its political stability and its consumption regime (Florentin, 2015).

ambivalences on the nature of infrastructure that are thereby carried along (Chapter 28). They particularly show how interventions on infrastructure such as maintenance activities blur the ontological frontiers of what an infrastructure is.

OPENINGS

This portrayal of genealogies of and ongoing conversations within urban infrastructure studies, we suggest, carries some lessons for future research in the field and invites speculations on how future infrastructure studies can best come to grips with (urban) infrastructural futures.

Lessons

Along the paths that were travelled over the last four decades, and certainly among those that will be explored in the coming years, our understanding of infrastructures has been, is being and will further be deeply transformed from the primarily engineering vision that prevailed until the early 1980s. Apprehending infrastructure as ecological and relational has been key to advance their understanding as social phenomena and processes.

In this introduction, we have evoked important avenues, milestones and crossroads.⁵⁰ The following chapters chart or suggest many directions for future urban infrastructure research. Indeed, as this introduction suggests and as the remainder of this book evidences, an infrastructure perspective is essential to academic, policy and political debates on most fundamental contemporary issues. How to foster emancipatory forms of sociality and creativity in the digital age? How to develop sustainable forms of human and more-than-human coexistence in the Anthropocene? How to restrain the currently powerful and liberticidal dynamics of social control, state coercion or structural violence? How to contain processes of commodification and prevent them from becoming ever more dominant and ever more ubiquitous? How to nurture forms of commoning, care or conviviality? These issues, deliberately formulated here from a progressive perspective, are in a fundamental way infrastructural issues. They call for the further development of infrastructure studies in order to investigate the variegated forms, processes and outcomes of infrastructural metamorphoses, and their significance in terms of prevailing forms of sociality, quests for social justice, economic participation, Earth's habitability and improvements in the (more than) human condition.

Speculations

In this scientific endeavour, the role of ecological crises will undoubtedly play a pivotal role. At a basic level, new climatic conditions will radically change the materiality of infrastructures, our abilities to maintain them and their functions in the face of frequent extreme weather events and consequently the modalities of their management. More fundamentally, climate change and other global environmental changes question the modernist 'infrastructural compact'. Indeed, as environmental historians have shown, the ongoing 'brutalisation'

⁵⁰ As Moss (2022) suggests, infrastructure studies are no longer the Cinderella of urban studies. This is, he argues, largely thanks to the 'fairy godmother's' intervention, namely the publication in 2001 of *Splintering Urbanism*.

of the relationship between human societies and the environment was historically fostered by infrastructures of different kinds, such as roads or extractivism-related technological systems (Bonneuil and Fressoz, 2016). This brutalisation has met with growing academic and social attention, leading to stimulating calls for the (democratic organisation of) decommissioning and removal of incumbent infrastructures, seen as ‘negative commons’ (Bonnet, Landivar and Monnin, 2021) or ‘obsolete urban forms’ (Wakefield, 2022), or even to calls for the sabotage of fossil infrastructures (Malm, 2021). Less radical at first sight, current political debates on the implementation of sufficiency policies in some infrastructural sectors such as water or energy in fact open promising research avenues pertaining to the very existence of infrastructures of sufficiency, the new modalities of sociality and the social contracts they may generate, and the ontological turn that a sufficiency-centred approach of infrastructure would entail.

Concomitantly, the fast, extensive and already far-reaching dynamic of digitalisation of infrastructures, artefacts, practices and regulatory devices keeps gaining momentum. In particular, more research will be needed to document, account for, analyse and assess the declining domination of one-size-fits-all infrastructures and the rise of individually tailored infrastructural environments. More generally, future research should further explore the ins and outs of the development of platform infrastructures or of the growing role of artificial intelligence in all things infrastructural.

One of the key contemporary epistemological and political challenges, we suggest, lies at the junction of those concomitant and partly contradictory dynamics. It consists in uncovering the potential plasticity of infrastructures – against the still dominant conceptualisation that emphasises infrastructural momentum and obduracy – and unleashing their heretofore hypothetical capacity to contribute to a ‘pacification’ of the relationship between human societies and the rest of the biosphere. Recent research, however, suggests that dominant forms of digitalisation and the specific cyborg perspective they entail go against such pacification. They would tend to make frugal infrastructures a pipe dream rather than a progressive horizon for a new urban condition.

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