Cities in an era of interfacing infrastructures: Politics and spatialities of the urban nexus

Jochen Monstadt [iD]
Department of Human Geography and Spatial Planning, Utrecht University, The Netherlands

Olivier Coutard
Ecole Nationale des Ponts et Chaussées, LATTS, France

Abstract
Over the last few years, nexus-thinking has become a buzzword in urban research and practice. This also applies to recent claims of greater integration or coordination of urban infrastructures that have traditionally been managed separately and have been unbundled. The idea is to better address their growing sociotechnical complexity, their externalities and their operation within an urban system of systems. This article introduces a collection of case studies aimed at critically appraising how concepts of nexus and infrastructure integration have become guiding visions for the development of green, resilient or smart cities. It assesses how concepts of nexus and calls for higher interconnectivity and 'co-management' within and across infrastructure domains often forestall more politically informed discussions and downplay potential risks and institutional restrictions. Based on an urban political and sociotechnical approach, the introduction to this special issue centres around four major research gaps: 1) the tensions between calls for infrastructure rebundling and the urban trends and realities driven by infrastructure restructuring since the 1990s; 2) the existing boundary work in cities and urban stakeholders' practices in bringing fragmented urban infrastructures together; 3) the politics involved in infrastructural and urban change and in aligning urban infrastructures that often defy managerial rhetoric of resource efficiency, smartness and resilience; and 4) the spatialities at play in infrastructural reconfigurations that selectively promote specific spaces and scales of metabolic autonomy, system operation (and failure), networked interconnectivities and system regulation. We conclude by outlining directions for future research.

Corresponding author:
Jochen Monstadt, Department of Human Geography and Spatial Planning, Faculty of Geosciences, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands.
Email: j.monstadt@uu.nl

摘要

在过去的几年里，关系（nexus）思维已成为城市研究和实践的流行语。这也适用于最近提出的、实现城市基础设施进一步一体化或协调的主张，这些基础设施传统上是分开治理的，而且未被捆绑。这个概念是为了更好地解决各类基础设施不断增长的社会技术复杂性、外部性和在由各城市系统构成的总体系统中的运营。本文介绍了一系列案例研究，旨在批判性地评估关联和基础设施整合的概念如何成为了绿色、复原性或智能城市发展的指导愿景。本文评估了关系的概念（以及在各基础设施领域内部和相互之间实现更高的互联性和"共同治理"的倡导）为何通常会阻止更多的政治知情讨论，并低估潜在的风险和制度限制。基于城市政治和社会技术方法，本期特刊的介绍围绕四个主要的研究空白领域：1）基础设施重新打捆的呼吁、与自20世纪90年代以来基础设施重组所造成的城市趋势和现实之间的张力；2）在整合零散的城市基础设施方面，城市现有的边界工作和城市利益相关者的做法；3）基础设施和城市变革以及协调城市基础设施方面的政治，这种政治往往违反资源效率、智能和复原力方面的管理学理论；4）基础设施重构方面的空间性，这会导致有选择地促进代谢自治的特定空间和规模、系统运行（和故障）、网络互连和系统调节。最后，我们概述了未来研究的方向。

关键词

环境/可持续性、治理、绿色、基础设施、政治、复原性和智能城市、技术/智能城市、城市和基础设施的变革

Introduction

This special issue builds on recent debates stretching across the academic policy spectrum on cities and sociotechnical change, and particularly on those concerning how we understand cities and advance urban studies through the lens of technical infrastructure. This approach reflects debates on the materiality of the city and the 're-materialisation' of urban studies as a fruitful way of thinking through reconfigurations of 'the urban' in the present (Amin and Thrift, 2002; Latham and McCormack, 2004; Rutherford, 2014). By focusing on the interplay of infrastructural and urban change, we can better grasp contemporary forms of change driven by global environmental pressures, systemic vulnerabilities and sociotechnical innovation (especially in relation to digital technologies), along with the resulting fixes for infrastructure investments. At the same time, we can explore recent policy shifts towards more resource-efficient, resilient or smart cities and interrelate those debates through an infrastructural perspective.

In this special issue, we argue that the study of the interconnectivities, interdependencies and multiple interfaces and hybrids between infrastructure domains is of critical interest to urban studies. Indeed, contemporary urban infrastructure displays an increasingly 'nested' character, with interacting resource flows, technological interconnections, operational and financial interdependencies and manifold governance interfaces at multiple scales. Those interactions do not only apply to single infrastructure domains (e.g. between different modes of transportation or between heating and electricity systems), but also to a 'nested system of systems' characterised by a variety of functional, ecological, technological, economic and political interlinkages between the domains of water and energy supply, solid waste management, sanitation, telecommunication and transport. Thus, the perspective

developed in this issue is designed to provide critical insight not only into understanding recent urban dynamics driven by environmental pressures, sociotechnical vulnerabilities and the spread of information and communications technologies (ICTs), but also into urban policy shifts towards more resource-efficient, resilient or smart cities and into recent appeals and initiatives for more integrative forms of co-management of urban infrastructures.

In spite of the recent interest in the interfaces between infrastructure domains and the calls for cross-sectoral management of infrastructures, urban studies have hitherto largely focused on single domains, and studies of infrastructure interfaces and interfacing are still rare (see Hansman et al., 2006; Little, 2002). For example, some scholars have studied the historical or contemporary development of sector-specific systems for water or energy supply, sewage or solid waste management, or the supply of telecommunications services. They have described the rise of the 'sanitary' or 'bacteriological' city (Gandy, 2006; Melosi, 2000), the 'electropolis' (Hughes, 1983), the 'hydropolis' (Frank and Gandy, 2006) or the 'cybercity' (Graham, 2003) in Europe and North America. These studies address the benefits and pitfalls of centralised infrastructure networks in shaping urban environments. Other scholars have analysed contemporary urban transitions of these sectoral systems towards allegedly more sustainable, and often more decentralised, sociotechnical configurations (e.g. the contributions to Coutard and Rutherford, 2016). While much of this research has focused on urban energy systems and their so-called low carbon transition (e.g. Bulkeley et al., 2011; Rutherford and Coutard, 2014; Monstadt and Wolff, 2015), others have examined infrastructural transitions in the provision of transportation (e.g. Affolderbach and Schulz, 2016), water and wastewater (e.g. Moss, 2000), solid waste (e.g. Wilts, 2016) and telecommunication services (e.g. Rutherford, 2005). Finally, the place-based urban environments and the diverse sociotechnical constellations beyond (or supplementary to) centralised infrastructure networks in the cities of the global South have also been scrutinised through the study of water supply or sanitation (e.g. Anand, 2017; Jaglin, 2005; Monstadt and Schramm, 2017), electricity (e.g. Luque-Ayala and Silver, 2016), telecommunications (e.g. Odendaal, 2011) and solid waste (e.g. Scheinberg et al., 2011). Those studies provide important insights into the major urban conditions and implications of the transformations at play in the various sectors. However, this special issue is based on the argument that integrated, cross-cutting approaches that critically look beyond individual domains and systematically address their cross-sector interactions, interfaces and hybridities are essential for a broader and better understanding of contemporary urban dynamics and conditions.

Debates on the urban nexus and nested infrastructure systems: Green, resilient and smart cities

Recent, largely policy-oriented debates on urban resource efficiency, urban resilience and smart city development across the global North and South point to the diverse ecological, financial, operational and institutional interactions, overlaps, interdependencies and hybridisations between the different infrastructure domains that shape urban development. According to those debates, innovations in individual domains cannot manifest themselves separately and autonomously; they rely on each other and co-evolve in their interrelationships with urban development, and are interwoven within the fabric of urban space. A major goal of many studies is to inform new policy, management and technological solutions in order to

better integrate interdependent infrastructures under the same decision-making framework and to enhance dialogue, collaboration and coordination across infrastructure (policy) domains. Their usual aim is a better understanding of how to manage urban interfaces, and to ensure that mutual benefits and tradeoffs are considered in decision-making and planning. Such integrated approaches thus seek to 'emphasize longer-term social and ecological sustainability while offering operational means to internalize externalities, foresee and mitigate unintended consequences, and above all, strengthen [...] open learning and institutional change' (Scott et al., 2015: 16).

Firstly, discourses on *green or resource-efficient cities* criticise traditional modes of pollution control focusing on a single environmental medium or environmental policy related to single sectors. In particular, recent policy and academic interest in the 'urban nexus' (Cairns and Krywoszynska, 2016; Cousins and Newell, 2015; GIZ and ICLEI, 2014; Williams et al., 2019) or 'urban symbioses' (Lenhart et al., 2015; Lorrain et al., 2018) has uncovered the complex energy and material flows across single domains as well as their material and technological interdependencies. They explore the ecological benefits of nexuses or symbioses between different infrastructure domains that have traditionally been managed separately. They address more integrated or circular approaches to close cycles of urban resources and waste and to reduce the ecological footprint of cities. Apart from environmental benefits, 'infrastructure integration' may potentially maximise returns on investment, minimise the costs of technological renewal and deliver a more citizen-focused approach to service provision (EEA, 2015). While the water–energy nexus has attracted the most attention, other examples are dry sanitary solutions, wastewater-to-energy generation or storage, electric mobility, ICT-based infrastructure solutions and water-based cooling systems.

Secondly, current policy and academic discourses on *smart cities* are encouraging new ICT-based interfaces across and between infrastructural domains, indicating the potential for integrated forms of monitoring of jointly provided services and new socio-technical interfaces between resource flows, networks and markets (Luque et al., 2014). ICTs and new sensing technologies are not expected solely to interlink the different providers and networks operators with the users, but also to provide new opportunities for a seamless cross-sector information, coordination and interconnection (Kanter and Litow, 2009), or for 'smart interfaces' between electricity and mobility, heating and waste(water), energy and water and other utilities. The shift from conventional to smart logics is thus accompanied by new expectations or promises of network flexibility, demand responsiveness, green growth, new services and connected communities (Luque-Ayala and Marvin, 2015) – and of better coordination within and across sectors.

Thirdly, debates on *resilient cities* portray cities as complex and interdependent systems and point to the growing vulnerability of modern urban societies through their infrastructural networks (e.g. Chang et al., 2014; Graham, 2010; Medd and Marvin, 2005). Those networks have become the metabolic systems of modern cities, triggering dramatic crises if they fail. The multiple threats to the seamless operation of infrastructures have been reinforced in recent years by weather extremes caused by climate change, terrorism or cyberattacks, thus increasing the vulnerability of cities to infrastructure failures or collapses. In addition, the increasing sociotechnical complexity of, and interdependencies between, infrastructure systems can provoke 'interactions, combinations, feedback loops, higher-order consequences,

and links across the system boundary' (Lovins and Lovins, 2001: 19). Hence, while interconnected infrastructure systems are seen as essential features that render cities desirable and indeed allow them to function at all, they also put cities at high risk. Due to the technical, functional and operational interconnectedness of critical infrastructures, these debates point to the risks of cascading failures in the event of breakdowns and call for cross-sectoral coordination (Collier and Lakoff, 2008; Little, 2002; Vertesi, 2014).

Exploring infrastructural interfaces and co-management

What all of these debates on resource-efficient, smart and resilient urbanisms have in common is that they are concerned with changing urban infrastructures and addressing their material, institutional and functional connectivities and overlaps. They illuminate the linkages between individual domains and expound the ecological, technological and social benefits (or limitations) of co-management. The literature in all three areas expounds on the challenges facing our water, energy, sewerage, waste and telecommunication systems, which together form a set of complex and above all interrelated systems and must be managed as such. The implication is that failure to do so could inadvertently create sub-optimal conditions that affect economic, national security or environmental concerns (Williams et al., 2014: 5): 'Hence, [urban] transformations or developments in one sector inevitably create reverberating repercussions, be they adverse or favourable, in other sectors' (Williams et al., 2014: 5).

Many proponents of those debates have hitherto focused on functional or technological benefits and applied both idealised and normative visions for the future of urban places, technological and social innovation and infrastructures. Much of the study of

urban resilience, resource efficiency and smartness has remained largely within the remit of managerial-level responses, based on simplistic notions of integrating or coordinating infrastructures that have traditionally been managed separately. Such scholarship tends to see technical infrastructures as primarily passive receptacles of policymaking, human action and the diffusion of functional technologies, and relegates urban materiality to the margins of the social world. In line with other approaches in urban studies, inspired by science and technology studies (Coutard and Guy, 2007; Hommels, 2005; Monstadt, 2009), we argue for the need to reconsider the role of technology in the production of 'resource-efficient, resilient and smart cities' and the urban politics of the processes of systemic transformation at play. Through this approach, we are not so much interested in the physical *objects* per se but more the varying social and material *relations* bound up in how these objects are used, experienced, performed, governed and understood in spatially different ways (cf. Rutherford, 2014: 1454). The connectivities, hybridisations or fragmentations of urban infrastructure are not just the result of a complex assemblage of policy ambitions, social practices, institutional arrangements, knowledge and values, but are also a set of artefacts whose materiality has both enabling and constraining effects on city development.

In this special issue, we analyse recent initiatives for more 'integration', coordination and 'co-management' within and across sectors. These are often based on overly simplistic assumptions that: a) complex (nexus) interdependencies could be understood objectively and independently from their specific historical, geospatial and sociopolitical contexts, and b) appropriate action from decision-makers would follow, once evidence-based knowledge had been provided to them (see Stein et al., 2014). Here,

we appraise how concepts of nexus and infrastructure integration have become an ultimate solution that forestalls more politically informed discussions while downplaying potential risks and institutional restrictions of an 'integrated' management of urban infrastructures. Based on an urban political and socio-*technical* approach, the special issue thus intends to address four major research gaps.

The unbundling and re-bundling of urban infrastructure domains

Several papers consider the tensions and articulations between, on the one hand, calls for integrating, re-bundling, hybridising and coordinating different domains of urban infrastructures, and, on the other, the urban trends and realities driven by infrastructure restructuring since the 1990s, which have been largely neglected by recent debates on urban co-management or integration. Various literatures have indicated trends towards an unbundling, rapid functional differentiation or 'splintering' of urban service provision (Coutard, 2008; Graham and Marvin, 2001) that needs to be considered more systematically in the study of resource-efficient, resilient and smart urban solutions. Many authors have indicated that the capability of city governments to coordinate infrastructure development across single domains has decreased over the last few decades in many global Northern cities. This is due first to the market- *and* policy-driven unbundling of urban utility services and second to the shifts from relatively coherent and equitable systems – based on the idea that infrastructures are economic 'natural monopolies' – to a complexity of fragmented institutional providers. The effects of these shifts include the emergence of new and independent infrastructure subsectors (e.g. the renewable energy supply and recycling industries); the aggressive entry of ICT firms

into the utility and urban service markets; the provision of new infrastructure services (e.g. energy efficiency services, financial products); the opening of local monopolies for new market players in liberalised markets; and the unbundling of formerly vertically integrated service providers and multi-utility services promoted by (trans)national liberalisation policies.

Against this background, Macrorie and Marvin (2019) discuss two major modalities ('computational' and 'ecological') of the contemporary 'guiding maxim' of integration, and analyse the associated forms of 're-bundling' of urban infrastructures that had previously been actively unbundled. They argue that current forms of 'bifurcated urban integration' are selective in their objects and outcomes and support a shift from 'horizontal', metropolitan-wide forms of socio-spatial integration to more selective logics of 'vertical' integration 'that privilege socially and spatially valued enclaves'. Thus, they argue, processes of unbundling and re-bundling, of disintegration and (re)integration, combine into yet another modality of infrastructural and urban splintering.

While more diversified sociotechnical arrangements increasingly challenge integrated forms of urban and infrastructure planning in the technological fabric of cities in the global North, the majority of urbanites located in the global South has, however, never benefited from integrated service provision. Instead, hybrid and splintered urban landscapes of networked service provision, private entrepreneurialism and local self-organisation characterise many urban areas in the global South (Coutard and Rutherford, 2016; Monstadt and Schramm, 2017). In this special issue, we advance that analysis one step further. We explore whether – and if so, under what conditions – the often more diverse, flexible, adaptive and redundant sociotechnical arrangements that work in a manner complementary to, at

the interstice of or in place of networked service provision may have a higher capacity to integrate new resource-efficient or 'smart' solutions. We wonder if they result in higher urban resilience, higher vulnerability or some combination of both.

For example, in their study of centralised waste-to-energy schemes in Hanoi, Vietnam, Schramm and Nguyen (2019) note that those centralised 'policies and plans have disregarded Hanoi's elaborate recycling industries which are intertwined with and overlap provincial waste and sanitation management and perpetually exist beyond state-led planning'. They further argue that: 'including alternative modes of nexusing into analyses of urban nexuses […] opens the view to possible contributions by established recycling industries to sustainable urban management and service provision and, at the same time, reveals the highly precarious nature of this work'.

In a similar vein, after describing 'the eviction of "non-modern" (informal) practices' of waste collection and sorting in the name of modern(ist) waste management schemes, de Bercegol and Gowda (2019) conclude that the performance of centralised waste incineration systems in Delhi, India, is 'mediocre from an energy, environmental and economic viewpoint, particularly given the mismatch between the technology and the composition of the waste produced'. While decentralised alternatives 'cannot realistically replace [large centralised systems] given the challenge of the colossal volumes of waste to be handled', they argue that they could efficiently complement them.

In a study of the reasons for the rapidly expanding use of ICTs in water and electricity supply in Nairobi, Kenya, Guma (2019) develops another perspective: in this case, infrastructure interfacing is strategically used to adapt to a splintered urban and infrastructural landscape. He argues that 'in recognition of the city's splintering and fragmentation, service providers have employed spatial targeting, strategically deploying "pro-poor" services'. Furthermore, 'while framed along narratives of spatial justice, "pro-poor" deployments demonstrate market-led priorities for utility providers in their desire to maximise returns on investment, expand centralised networks, increase market share, and counter competition from private and heterogeneous providers'. In this regard, 'ICT-based options have allowed utility providers to apply spatial targeting as a niche-based strategy aimed at specific [often low-income] user groups and areas.' And yet 'these solutions have become subject to micro-politics, contestation and sometimes disengagement on the part of urban residents intent on recalibrating and re-appropriating them to fit their everyday lives'. More generally, there is an urban political dimension to pro-poor service nexusing in African cities that needs to be further examined.

Boundary work and intermediation practices across infrastructure domains

Contributions to this special issue argue that much 'boundary work' and intermediation can be observed in cities, where individuals – engineers, operators, policymakers, planners, NGO workers and users – act to bring fragmented urban infrastructures together in order to produce multi-infrastructural interaction, hybridisation and coordination. Examples of such multi-infrastructural work across heterogeneous systems range from reorganisations in municipal companies to develop cross-sector coordination in planning, financing, operations or maintenance; to high-tech symbiosis-based 'solutions' at the building or neighbourhood scale; and to greater scale developments such as large waste-to-energy or wastewater-to-energy facilities. Contributions to this special issue do not solely seek to advance our empirical and conceptual understanding of infrastructural heterogeneity, differentiation and

splintering, or of urban obduracy and path dependencies. Instead, we centre our analytical interest on infrastructural work as practice: the work of engineers, policymakers, planners, users and others, which are both situated within and produce urban realities. The articles are thus concerned with the messy, controversial and conflicting production, reproduction and transformation of urban infrastructure through various overlaps, interconnections and symbioses with other systems. In particular, they focus on how and where actors actually make connections and bring disparate infrastructure systems together, and on how different artefacts come to matter to the various interest groups involved in making sustainable, resilient and smart cities. By doing so, they reveal how urban actors and their practices encounter and change infrastructures in deployment or develop new infrastructural arrangements.

Moss and Hüesker (2019), for example, examine the significant and diverse challenges faced and addressed by urban wastewater utilities aiming to enter the regional energy provision market as energy flexibility providers. They identify four main types of challenges: *material* challenges related 'not only [to] flows of energy and wastewater but also [to] the physical structures used to treat and transport them'; *spatial* challenges associated with 'the multiple geographies at play' in interactions with the energy markets; *political* challenges raised by the redistribution of power among (incumbent and new) actors; and *temporal* challenges resulting from the necessity to 'align', within and between infrastructural sectors, 'a variety of temporalities ranging from real-time energy flows to long-term infrastructure investment plans'.

Florentin (2019) focuses on the transformation of the Städtische Werke Magdeburg (SWM) in Germany into a 'cross-utility' aimed at devising a common strategy for all of its infrastructure networks. He emphasises the boundary work involved (emblematised by the weekly Monday meetings gathering together all members of the networks' management team) and the ambiguities of this transformation. He acknowledges that 'the transformation of the multi-utility into a cross-utility enables new forms of collaborations and synergies that were formerly neglected and can be deepened, transforming and strengthening its role in the urban arena'. At the same time, he stresses that 'like any transformation of these socio-technical objects, this transformation shift[ed] tensions or generate[d] new ones, within and outside the utility', as illustrated by what some SWM staff members view as the systematic prioritisation of energy over water in their strategy and by the trade-offs between the waste-to-energy and the waste reduction policies.

Focusing on the governance of critical infrastructures aimed at improving urban resilience against major infrastructure failures, Monstadt and Schmidt (2019) emphasise another form of boundary work shared among a broad array of public and private actors spanning 'often fragmented, policy domains and territories and institutionally unbundled utility (sub-)domains'. The 'wicked problem' at stake faces an 'institutional void', that is, the lack of generally accepted rules and procedures, reinforced by what the authors frame as an 'interdependency paradox'. While all stakeholders emphasise that 'interdependency management' and cross-sector cooperation are essential to the increasingly complex governance of critical infrastructure, 'they tend to focus on incremental amendments within their own jurisdiction and area of responsibility' and thus exhibit cognitive and institutional restrictions to organising such cooperation. The article explores the work involved in, or required for, solving this paradox.

In their careful study of the implications of the introduction of hot water metering in a number of dwellings in Linköping,

Sweden, Rohracher and Köhler (2019) show how hot water meters enact a form of boundary work between energy and water systems. Their study finds that households operate as a nexus in which energy and water are recombined through specific user practices. This work leads in partially unintended directions, such as when their introduction results in the (inefficient) disconnection of dishwashers from warm water.

Contributors also sometimes point to 'missing' boundary work. de Bercegol and Gowda (2019), for instance, point to the multiple forms of coordination that seem desirable between centralised and informal waste management systems: compost production at the neighbourhood level, door-to-door collection and sorting by informal waste pickers, all accompanied by appropriate treatment of residual waste.

The articles thus suggest, in line with Vertesi (2014), that there are many possible ways to patch multiple systems together into place-based urban constellations: 'In this way, multi-infrastructural work across heterogeneous systems becomes […] a kind of ad hoc patchwork. It is a sort of lay practice of heterogeneous engineering […] that produces fleeting alignment or misalignment of infrastructures to accomplish local, mundane tasks' (Vertesi, 2014: 269).

In fact, this special issue presents urban cases in which actors actively search for, explore and reflect place-based and often conflictive urban practices that in turn address the complex interaction with the 'nested system of systems' of urban infrastructure provision.

The urban politics of infrastructure alignment

The articles in this themed issue address the politics that are involved in aligning urban infrastructures. Going beyond the apparently consensual managerial rhetoric of resource efficiency, smartness and resilience, they unearth the power relations and interests at play in processes of urban reconfiguration, and the groups gaining and losing from them. Three facets of those reconfigurations deserve particular attention (Coutard and Rutherford, 2016). First, there are the conditions and processes involved in the emergence of novel ways of evaluating and accounting for resource flows (energy, water, waste, data) that in turn play a key role in the urban political economies and ecologies of new infrastructural configurations. Second, the transformations in the everyday lives and experiences of urban dwellers in urban and infrastructural environments are reshaped and reshuffled (see also Graham and McFarlane, 2015). Third, infrastructural issues re-emerge as urban problems and forms of individual and collective appropriation and mobilisation of infrastructures. These articles are thus especially concerned with, for example, which resources are re-bundled, by which means, by whom, to the benefit or detriment of whom; how processes of integration are initiated, by whom, with what objectives and whether the stakeholders and objectives (or how they are implemented) evolve along the process; and how, by whom and with what effects novel urban infrastructural configurations are appropriated.

Schramm and Nguyen (2019), for example, conclude from their analysis of centralised waste-to-energy schemes in Hanoi that: 'the very definition of 'waste' is at stake as policy-makers and urban planners strive to create a centralised system of waste incineration in the name of sustainability. This new attempt to redefine specific materials as waste and consequently who gets to process, transform or recycle these materials, is a political project, as it is exclusive and has the potential to disturb, marginalise or even destroy existing industries of waste recycling in Hanoi.'

Based on the example of the Thames Tideway Tunnel (TTT) megaproject, Loftus and March (2019) argue that strong financialisation logics and interests are at play in contemporary infrastructure development and that these interests 'run counter to many of the principles guiding the new wave of integration'. The TTT terminates at the Beckton plant, 'described as the UK's Water–Energy–Food nexus poster child, for its combination of desalination facilities, green energy generation and wastewater treatment'. Yet the authors note that 'while physically connected to the Beckton plant, the TTT is, paradoxically, designed with an apparent disregard for the water–energy nexus'. Indeed, 'the degree to which energy generation at Beckton can keep up with the demands of such large-scale schemes is far from certain'. Financial, rent-extraction logics privilege large-scale infrastructure projects and while: 'there are alternatives, more integrated and less costly ones […] these alternatives do not provide such fertile terrain for rent extraction. Differing visions of integration [thus] come to be contested within the differing viewpoints of how best to respond to a polluted Thames.'

The TTT thus appears as the outcome of financial interests' domination over cross-sector integration.

Rohracher and Köhler (2019) note that the introduction of hot water metering in Linköping households raised various controversies regarding the fair reallocation of costs between multiple stakeholders (e.g. inefficient and efficient resource users, the housing company and tenants). The resistance to the introduction of metering was thus seen by some residents as an expression of solidarity with larger families or with residents in deprived parts of the city. Moreover, in the context of an 'increased corporatisation and neo-liberally inspired management, questions of trust in the public housing company came to the fore'. The

authors conclude that 'as contested political terrains, new couplings between infrastructure and resource systems […] become an arena where urban change and visions of urban futures are negotiated'. Additionally, Florentin (2019) emphasises that political processes of power redistribution not only operate *between* stakeholder organisations, between groups in urban societies or between incumbents and newcomers, but also *within* incumbent organisations: local or state administrations, public organisations, private firms. Taken together, the articles show that politics are ubiquitous in infrastructure interfacing processes. They may take many diverse forms and operate on multiple scales.

The spatialities of urban infrastructure re-bundling

Finally, there is a spatiality to the transformations at play. The development of large-scale technological networks has been key in the emergence of networked and relational forms of territoriality in which connection-based spatially distant interactions (vs. contiguity-based interactions) play an ever-increasing role (Dupuy, 2008; Offner, 2000; Raffestin, 1980). Within networked societies (Castells, 1996), the nature of the city evolves. The size, density and heterogeneity of populations and activities that were identified as key dimensions of the pre-modern and modern city have been progressively paralleled by the size, density and heterogeneity of connections. Additionally, the spatial expansion of large networks has supported the advent of 'generalised' (Choay, 1994) or 'planetary' (Brenner, 2014) urbanisation. However, the spatial scale and network topologies vary considerably in different infrastructure domains. The emergent interdependencies, interactions and hybridisations between infrastructure domains might thus invoke a new and complex

spatiality of interconnectivities and interdependencies, and blur the boundaries between different geo-political spaces (Medd and Marvin, 2005) that have barely been studied yet. Several articles herein examine whether current infrastructural reconfigurations selectively promote specific spaces and scales of metabolic autonomy, system operation (and failure), networked interconnectivities and interdependencies, and system regulation. Hence, as noted above, Macrorie and Marvin (2019) emphasise the socio-spatial selectivity of what they call 'bifurcated urban integration'. Moreover, contributors also consider whether, and if so how, such scalar or spatial changes and re-orderings affect the forms and scales of urban spatialities more broadly.

Moss and Hüesker (2019), for example, remark that the urban initiatives aimed at integrating urban wastewater and regional energy systems 'are not about making the city itself more self-sufficient or renewable in its energy generation, but about connecting the energy produced or stored in the city to networks operating at regional and transregional scales'. As expressed in new business alliances, inter-municipal collaboration and material flows, the authors uncover new spatial relations between cities and spaces which create inter-scalar synergies (e.g. between municipal utilities and the national association for energy and water), but also scalar mismatches (e.g. between localised wastewater treatment plants and regionally oriented grid operators).

Monstadt and Schmidt (2019) argue that the required improvements in the urban governance of critical infrastructures and in the prevention of and preparedness for major infrastructure failures are cross-scalar issues. They cannot be addressed 'solely at the municipal level. Equally important are national and European regulations that reflect more adequately on the "wicked" problems of urban infrastructure

governance, [including] the re-assessment of neoliberal market reforms' that largely created the fragmented landscape of institutions in charge of infrastructures in the first place.

Studying the development over nearly a century and a half of the water and electricity 'infrastructure landscapes' of Bangalore, India, Castán Broto and Sudhira (2019) demonstrate how the two infrastructure systems co-evolve and shape each other at different scales (household, broader urban context, extra-urban connections). They also show how this evolving infrastructural landscape shapes spatial inequalities and increases differentiation of modes of living across the city, thus revealing the 'interconnectedness of the mechanisms of infrastructure governance and urban inequality'.

Interfacing infrastructures, the construction of urban futures and the shaping of urban infrastructure research

In the above-mentioned ways, the special issue speaks to and engages with important concepts of resource-efficient, resilient and smart cities that have featured prominently in urban studies and geography journals. It does so by exploring how they are shaped by the interactions, hybridisations (or dissolutions) and co-management of different infrastructure domains, or by coordinated (or segmented) forms of urban governance; and how they shape recurrent socio-spatial vulnerabilities and urban environments across the 'global North' and 'global South'. The authors investigate how those notions are being differently interpreted, translated, experienced and grounded in (and through) context-specific responses and policies, and the repercussions thereof on cities and infrastructures around the world. Equally important is that policymakers, utility companies

and users within cities also have varying capacities, capabilities and motivations to foster such integration, 're-bundling' or hybridisation of segmented infrastructures. A central contribution of the special issue is its critical analysis and theorising of normative notions of the re-bundling of urban infrastructures and its illustration of how those infrastructures are shaped by urban materialities, policies, practices and uses in cities that shape them in return. These contributions not only locate urban infrastructural transitions within a multilevel (governance) framework, but they also underscore how the diverse challenges to resource-efficient, resilient or smart infrastructure become, or may become, central components in broader, ongoing and technologically mediated *urban* transformations.

Drawing on empirical research conducted in sites throughout the global North and South, the articles shed light on a series of relationships that intertwine cities and infrastructure: the relationships, interaction and symbioses between different urban technologies, utility companies and infrastructure policies and how functional, technical, ecological and institutional interfaces shape urban development. Contributors all share the conviction that the materialities and social practices involved with complex interdependencies and interfaces between different infrastructure domains require more critical attention in both urban studies and urban policy initiatives. At a time of increasing policy, (social) scientific and public interest in the governance, production, management and use of infrastructure services, the articles gathered here offer a timely and relevant perspective on questions that will be central to urban futures throughout the 21st century.

In doing so, the articles also point to five important but as yet insufficiently explored research directions:

Urban system of systems thinking: One of the most powerful ways of deciphering urban change is to study cities' technical infrastructures. Faced with current urban challenges such as resilience and ecological sustainability or the rise of ICTs as superstructures in the operation of other infrastructure domains, the contributions point to the fact that urban studies and planning must reconsider their approaches and must address individual infrastructures as urban systems of systems that *together* shape urban futures. More attention thus needs to be paid to the cumulative impacts of infrastructural change within individual domains, but also to their ecological and material, financial, regulatory interfaces and interdependencies, synergies, frictions and conflicts.

Effective nexusing: As a whole, these articles demonstrate that in spite of a pervasive nexus and 'urban integration' rhetoric and apart from the specific form of nexusing that consists in the rapid 'smartification' of the various infrastructure sectors, actual achievements in infrastructural interfacing remain marginal by most standards: metabolic, technical, financial, organisational, institutional etc. This 'implementation gap' has been explored in many of the articles, but the lasting paradox between enthusiastic pro-integration claims and the observable reluctance of the utility industries in particular to pursue the (potential) benefits from this new growth niche in the infrastructure sector remains to be fully understood and assessed.

Progressive nexusing: Clearly emerging from this collection is the contingent outcome of infrastructure interfacing, in economic, ecological, socio-spatial or resilience terms. This opens a research area on the primarily institutional conditions under which more progressive configurations of provision of infrastructure service can be identified and promoted.

Households as nexus: At least two articles (Castán Broto and Sudhira, 2019; Rohracher and Köhler, 2019) emphasise the role of households, domestic spaces and domestic practices in the actual interfacing of otherwise little integrated infrastructure systems. The growing scientific evidence supporting the importance of the mutual shaping of infrastructures and everyday practices (Shove and Trentmann, 2018) and the inherently cross-scalar nature of infrastructures in use, from the body to the planet and back, is a strong invitation to integrate the household level fully in future studies of infrastructures and nexusing.

Temporalities of nexusing: Interfacing projects or processes bring out a crucial but often overlooked specificity of infrastructures: their multiple temporalities, from the complexities of real-time operation to the slow dynamics and path dependencies of changes in infrastructurised practices. From the long-term periods of infrastructure planning, development and restructuring to their ever ongoing reconfiguration and maintenance to infrastructural futures in their various guises: all of these elements can slowly grow or suddenly emerge, be planned or incrementally executed, longed for or feared. At a time when the future is crowding the present to such a remarkable extent and when tensions between day-to-day actions and long-term challenges are particularly acute, the multiple temporalities of infrastructures deserve close attention as a way to better understand, and possibly act upon, the multiple time-related conundrums faced by contemporary cities and societies.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ORCID iD

Jochen Monstadt https://orcid.org/0000-0001-9146-1571

References

Affolderbach J and Schulz C (2016) Mobile transitions: Exploring synergies for urban sustainability research. *Urban Studies* 53(9): 1942–1957.

Amin A and Thrift N (2002) *Cities: Reimagining the Urban*. Cambridge: Polity Press.

Anand N (2017) *Hydraulic City: Water and the Infrastructures of Citizenship in Mumbai*. Durham, NC: Duke University Press.

Brenner N (2014) *Implosions/Explosions: Towards a Study of Planetary Urbanization*. Berlin: Jovis.

Bulkeley H, Castan Broto V, Hodson M, et al. (eds) (2011) *Cities and Low Carbon Transitions*. London: Routledge.

Cairns R and Krywoszynska A (2016) Anatomy of a buzzword: The emergence of 'the water-energy-food nexus' in UK natural resource debates. *Environmental Science & Policy* 64: 164–170.

Castán-Broto V and Sudhira HS (2019) Engineering modernity: Water, electricity and the infrastructure landscapes of Bangalore, India. *Urban Studies* 56(11): 2261–2279.

Castells M (1996) *The Rise of the Network Society: The Information Age. Economy, Society and Culture*. Vol. 1. Oxford: Wiley-Blackwell.

Chang SE, McDaniels T, Fox D, et al. (2014) Toward disaster-resilient cities: Characterizing resilience of infrastructure systems with expert judgments. *Risk Analysis* 34(3): 416–434.

Choay F (1994) Le règne de l'urbain et la mort de la ville. In: Dethier J and Guiheux A (eds) *La ville. Art et architecture en Europe, 1870–1993*. Paris: Editions du Centre Pompidou, pp. 26–35.

Collier SJ and Lakoff A (2008) Distributed prepa-
redness: The spatial logic of domestic security
in the United States. *Environment and Planning
D* 26(1): 7–28.

Cousins JJ and Newell JP (2015) A political-
industrial ecology of water supply infrastruc-
ture for Los Angeles. *Geoforum* 58: 38–50.

Coutard O (2008) Placing splintering urbanism:
Introduction. *Geoforum* 39(6): 1815–1820.

Coutard O and Guy S (2007) STS and the city:
Politics and practices of hope. *Science, Tech-
nology, & Human Values* 32(6): 713–734.

Coutard O and Rutherford J (eds) (2016) *Beyond
the Networked City: Infrastructure Reconfi-
gurations and Urban Change in the North and
South*. London: Routledge.

de Bercegol R and Gowda S (2019) A new waste
and energy nexus? Rethinking the modernisa-
tion of waste services in Delhi. *Urban Studies*
56(11): 2297–2314.

Dupuy G (2008) *Urban Networks – Network
Urbanism*. Amsterdam: Techne Press.

EEA (European Environment Agency) (2015)
*Urban sustainability issues – Enabling resource-
efficient cities*. Technical report No 25/2015.
Copenhagen: European Environment Agency.

Florentin D (2019) From multi-utility to cross-
utilities: The challenges of cross-sectoral entre-
preneurial strategies in a German city. *Urban
Studies* 56(11): 2242–2260.

Frank S and Gandy M (eds) (2006) *Hydropolis.
Wasser und die Stadt der Moderne*. Frankfurt
am Main: Campus.

Gandy M (2006) The bacteriological city and its
discontents. *Historical Medical Geography*
34(1): 14–25.

GIZ and ICLEI (German Development Coopera-
tion and Local Governments for Sustainabil-
ity) (2014) *Operationalizing the Urban
NEXUS: Towards Resource-Efficient and Inte-
grated Cities and Metropolitan Regions*.
Eschborn: GIZ/ICLEI.

Graham S (ed.) (2003) *The Cybercities Reader*.
London and New York: Routledge.

Graham S (ed.) (2010) *Disrupted Cities – When
Infrastructure Fails*. London and New York:
Routledge.

Graham S and McFarlane C (eds) (2015) *Infra-
structural Lives: Urban Infrastructure in Con-
text*. London: Routledge.

Graham S and Marvin S (2001) *Splintering
Urbanism: Networked Infrastructures, Techno-
logical Mobilities and the Urban Condition*.
London: Routledge.

Guma PK (2019) Smart urbanism? ICTs for water
and electricity supply in Nairobi. *Urban Stud-
ies* 56(11): 2333–2352.

Hansman RJ, Magee C, De Neufville R, et al.
(2006) Research agenda for an integrated
approach to infrastructure planning, design
and management. *International Journal of
Critical Infrastructures* 2(2/3): 146–159.

Hommels A (2005) Studying obduracy in the
city: Toward a productive fusion between
technology studies and urban studies. *Sci-
ence, Technology and Human Values* 30(3):
323–351.

Hughes TP (1983) *Networks of Power: Electrifica-
tion in Western Society 1880–1930*. Baltimore,
MD: Johns Hopkins University Press.

Jaglin S (2005) *Services d'eau en Afrique subsa-
harienne: La fragmentation urbaine en question*.
Paris: CNRS Editions.

Kanter RM and Litow SS (2009) Informed and
interconnected: A manifesto for smarter cities.
Working Paper 09–141, Harvard Business
School.

Latham A and McCormack D (2004) Moving cit-
ies: Rethinking the materialities of urban geo-
graphies. *Progress in Human Geography* 28(6):
701–724.

Lenhart J, Van Vliet B and Mol APJ (2015) New
roles for local authorities in a time of climate
change: The Rotterdam Energy Approach and
Planning as a case of urban symbiosis. *Journal
of Cleaner Production* 107: 593–601.

Little RG (2002) Controlling cascading failure:
Understanding the vulnerabilities of intercon-
nected infrastructures. *Journal of Urban Tech-
nology* 9(1): 109–123.

Loftus A and March H (2019) Integrating what
and for whom? Financialisation and the
Thames Tideway Tunnel. *Urban Studies*
56(11): 2280–2296.

Lorrain L, Halpern C and Chevauché C (eds)
(2018) *Villes sobres. Nouveaux modèles de gestion
des ressources*. Paris: Presses de Science Po.

Lovins A and Lovins LH (2001) *Brittle Power.
Energy Strategy for National Security*. 2nd
edn. Andover, MA: Brick House Publishing.

Luque-Ayala A and Marvin S (2015) Developing a critical understanding of smart urbanism? *Urban Studies* 52(12): 2105–2116.

Luque-Ayala A and Silver J (eds) (2016) *Energy, Power and Protest on the Urban Grid: Geographies of the Electric City*. Abingdon: Routledge.

Luque A, McFarlane C and Marvin S (2014) Smart urbanism – Cities, grids and alternatives? In: Hodson M and Marvin S (eds) *After Sustainable Cities?* London: Routledge, pp. 75–90.

Macrorie R and Marvin S (2019) Bifurcated urban integration: The selective dis- and reassembly of infrastructures. *Urban Studies* 56(11): 2207–2224.

Medd W and Marvin S (2005) From the politics of urgency to the governance of preparedness: A research agenda on urban vulnerability. *Journal of Contingencies and Crisis Management* 13(2): 44–49.

Melosi M (2000) *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. Baltimore, MD: Johns Hopkins University Press.

Monstadt J (2009) Conceptualizing the political ecology of urban infrastructures: Insights from technology and urban studies. *Environment and Planning A* 41(8): 1924–1942.

Monstadt J and Schmidt M (2019) Urban resilience in the making? The governance of critical infrastructures in German cities. *Urban Studies* 56(11): 2353–2371.

Monstadt J and Schramm S (2017) Toward the networked city? Translating technological ideals and planning models in water and sanitation systems in Dar es Salaam. *International Journal of Urban and Regional Research* 41(1): 104–125.

Monstadt J and Wolff A (2015) Energy transition or incremental change? Green policy agendas and the adaptability of the urban energy regime in Los Angeles. *Energy Policy* 78: 213–224.

Moss T (2000) Unearthing water flows, uncovering social relations: Introducing new waste water technologies in Berlin. *Journal of Urban Technology* 7(1): 63–84.

Moss T and Hüesker F (2019) Politicised nexus thinking in practice: Integrating urban wastewater utilities into regional energy markets. *Urban Studies* 56(11): 2224–2241.

Odendaal N (2011) Splintering urbanism or split agendas? Examining the spatial distribution of technology access in relation to ICT policy in Durban, South Africa. *Urban Studies* 48(11): 2375–2397.

Offner JM (2000) 'Territorial deregulation': Local authorities at risk from technical networks. *International Journal of Urban and Regional Research* 24(1): 165–182.

Raffestin C (1980) *Pour une géographie du pouvoir*. Paris: Edition Litec.

Rohracher H and Köhler H (2019) Households as infrastructure junctions in urban sustainability transitions – the case of hot water metering. *Urban Studies* 56(11): 2372–2386.

Rutherford J (2005) Networks in cities, cities in networks: Territory and globalisation intertwined in telecommunications infrastructure development in Europe. *Urban Studies* 42(13): 2389–2406.

Rutherford J (2014) The vicissitudes of energy and climate policy in Stockholm: Politics, materiality and transition. *Urban Studies* 51(7): 1449–1470.

Rutherford J and Coutard O (2014) Urban energy transitions: Places, processes and politics of socio-technical change. *Urban Studies* 51(7): 1353–1377.

Scheinberg A, Spies S, Simpson MH, et al. (2011) Assessing urban recycling in low- and middle-income countries: Building on modernised mixtures. *Habitat International* 35(2): 188–198.

Schramm S and Nguyen M (2019) Turning waste into resources and resources into waste: Centralized waste-to-energy nexuses and alternative modes of nexusing in Hanoi. *Urban Studies* 56(11): 2315–2332.

Scott CA, Kurian M and Wescoat JL (2015) The water-energy-food nexus: Enhancing adaptive capacity to complex global challenges. In: Kurian M and Ardakanian R (eds) *Governing the Nexus: Water, Soil and Waste Resources Considering Global Change*. Cham: Springer, pp. 15–38.

Shove E and Trentmann F (eds) (2018) *Infrastructures in Practice: The Dynamics of Demand in Networked Societies*. London: Routledge.

Stein C, Barron J and Moss T (2014) Governance of the nexus: From buzz words to a strategic action perspective. Nexus Network Think Piece Series, Paper no. 3, Brighton.

Vertesi J (2014) Seamful spaces: Heterogeneous infrastructures in interaction. *Science, Technology & Human Values* 39(2): 264–284.

Williams J, Bouzarovski S and Swyngedouw E (2014) Politicising the nexus: Nexus technologies, urban circulation, and the coproduction of water-energy. Nexus Network Think Piece Series, Paper no. 1, Brighton.

Williams J, Bouzarovski S and Swyngedouw E (2019) The urban resource nexus: On the politics of relationality, water–energy infrastructure and the fallacy of integration. *Environment and Planning C: Politics and Space* 37(4): 652–669.

Wilts H (2016) *Nachhaltige Innovationsprozesse in der kommunalen Abfallwirtschaftspolitik – eine vergleichende Analyse zum Transition Management städtischer Infrastrukturen in deutschen Metropolregionen.* Hamburg: Kovacrlag.