DOI:10.1111/1468-2427.12528

# SYMPOSIUM

## ENGINEERING CITIES: Mediating Materialities, Infrastructural Imaginaries and Shifting Regimes of Urban Expertise

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### Abstract

*This symposium opens up new critical insights and analytical perspectives into the relationships between power, politics, materiality and urban engineering. In so doing it demonstrates the central role of engineers in the production and negotiation of everyday life in the city. In contrast to the technocratic exercise engineering often professes to be, the contributors to this symposium argue that the assembling and choreography of cities through the myriad techniques, routines, standards and visions of engineers is inextricably bound up with broader socio-cultural, material and political urban dynamics and processes. This necessitates investigating the multiple and competing social imaginations, forms of knowledge and regimes of expertise associated with urban engineering. The symposium's five articles, straddling disciplinary backgrounds in geography, anthropology, engineering and history, focus analytical and empirical attention on the figure of the engineer and on the work of engineering in the cities of Paris, Mumbai, Singapore and London. Engineering, we suggest, is a diagnostic for probing the shifting forms of mediation that animate and inhabit contemporary dynamics of urban change. The symposium thus opens up a new avenue for cross-disciplinary and transregional research for urban studies while also suggesting innovative ways of conceptualizing urban transformation and contestation.*

### Introduction

Cities are made and unmade by engineers and engineering. Piped water, telephone networks, transport infrastructure, internet systems, sewage disposal, acoustic environments, electrical provision and atmospheric comfort all depend on the specialized knowledge and everyday work of engineers. Design, installation and maintenance of pipes, wires, tarmac, software, drains, machinery, fuses, tracks, bridges and buildings enable the day-to-day functioning (and malfunctioning) of cities across geographical and historical contexts. Far from the technocratic exercise it sometimes professes to be, the engineering of city life—through myriad techniques, routines, regimes of knowledge, material practices and social imaginings—is inextricably bound up with broader processes of spatial representation, political contestations and urban change.

 Many thanks to Ankit Bhardwaj, Greet de Block, Kate Crawford and Anthony Levenda for their suggestions and to the three anonymous IJURR reviewers for their helpful comments. This article draws from a research project entitled 'Vertical Urbanism: Geographies of the Mumbai Flyover', funded by ESRC Grant RES-000-22-3127.

Notwithstanding the central role of engineering in what Thomas Osborne (1996: 114) calls 'the city's condition of existence', urban studies has not directly interrogated the work of engineers in urban life. The engineer is rarely treated as an important urban archetype on a par with the taxi driver, detective, strongman, politician, bureaucrat, rag-picker, bohemian, prostitute, builder, street hawker or criminal. Where urban ethnography has featured engineers, it has largely done so without explicitly attending to the relation between individual characters as distinct urban figures (that is, as city engineers) and the 'ground' against which the engineer as a figure becomes meaningful.[1] Critical research that has emerged over the past two decades on urban infrastructure, urban metabolism, splintering cities and cyborg urbanization has similarly paid little close attention to engineers and engineering (see e.g. Graham and Marvin, 2001; Gandy, 2004; 2005). Perhaps the work of engineering—what Coutard (1999: 1) calls 'engineers' stuff' and which both Gandy (2014: 16) and Graham and Marvin (2001: 102) describe as 'arcane'—remains uninterrogated because it is seen as defined and circumscribed by technical expertise, applied science and positivist impulses, and is thus presumed an uninteresting or unimportant site for critical scholarly inquiry. When engineering does feature in urban research it is often treated as a metaphor rather than as an actual practice (see e.g. Amin and Thrift, 2002: 93, on the 'engineering of certainty'; McFarlane, 2008: 418, on 'socio-material engineering' and Adey, 2008, on the 'engineering of affect').

Even in science and technology studies (STS), where cities have been seen as spaces of experimentation and laboratorization (e.g. Karvonen and van Heur, 2014), research has tended to focus on scientists and architects rather than engineers and engineering (although, see Latour, 1987; Law and Callon, 1988; Latour, 1996; Bijker, 2007). There has been important work on large technological systems (e.g. Hughes, 1983), a growing body of research focusing on the politics of geo-engineering in environmental geography (e.g. Yusoff, 2013) and careful ethnographic studies of engineering practices and knowledges within anthropology (e.g. Harvey and Knox, 2013). However, this has infrequently intersected directly with work on urbanism per se. Research in engineering studies, for its part, has tended to focus on education and professional associations (e.g. Brown, Downey and Diogo, 2009), on engineering cultures (e.g. Kranakis, 1997) and on the relationships between engineering, modernity and nationalism (e.g. Lucena, 2007) rather than on cities and urbanization.

This symposium focuses analytical and empirical attention on city engineers and on engineering cities to bring urban theory and research into dialogue with insights from material anthropologists, STS scholars, and historians of engineering who have studied engineering directly. The five articles in this symposium examine engineers and engineering in the particular (and different) urban contexts of Paris, Mumbai, Singapore and London. The symposium straddles disciplinary backgrounds in geography, anthropology, engineering and history to open up new critical insights and analytical perspectives into the relationships between power, knowledge, materiality, imagination and everyday practice, demonstrating the key role of engineers in the production, contestation and *mediation* of the urban. This introductory article lays the groundwork for the five articles by exploring the work of engineers and engineering in myriad, often conflicting articulations of urban authority and 'stateness' (Painter, 2006), as well as in accompanying competing ideals and aspirations of urban modernity and 'globality'. While recognizing how 'the operation of the idea of the engineer matters (and has always mattered) in the domination of space' (Kirsch, 1995: 551), we suggest how the optic of engineering calls analytical, theoretical and methodological attention to material politics, to contingent and contextual practices, and to broader social and cultural imaginations. Engineering, we argue, is a diagnostic for probing the shifting

1 Here we take a cue from Barker *et al.*'s (2013: 160) call for explicit empirical and analytical attention to the 'meaning-making relationship between figure and ground'.

forms of mediation that animate and inhabit contemporary dynamics of urban socio-spatial transformation and material contestation.

We begin this introductory article by exploring engineering's central and integral role in processes of urban statecraft, in the fabrication of modern ideals of the orderly and healthy metropolis, and in creating new forms of globalized space. However, rather than charting a straightforward relationship between engineering and shifting dynamics of urban power and authority, the article's next two sections emphasize the contingent, contextual and experiential forms of interconnection that shape and define engineering theory, knowledge, practice and action. Engineering is not only embedded in particular institutional and cultural settings, but involves the continual negotiation of often conflicting scientific, technical, financial and political realms. This location of engineering across myriad contexts, knowledge regimes and experimental practices requires, as we argue in the following section, engagement with urban scholarship that is attentive to the political significance of materials, forms of distributed expertise and the work of the social imagination. This is particularly crucial, we conclude, given recent shifts towards digital technologies, smart city fantasies and audit cultures in processes of city making that are recalibrating and reimagining the role and place of urban engineering.

## Engineering urban power: statecraft, modernity and globality

Despite the reputation of 'engineering' as a politically innocent, technocratic kind of expertise that is above partisan wrangles (or perhaps precisely because of this reputation) the modern engineering profession has from its inception been bound up with power-infused processes of socio-spatial and material transformation. As Andrew Barry (2005: 94) argues, 'far from having anti-political effects, the calculations of engineers [have] had political resonances'. Engineering technologies and practices have been shown to be integral to new forms of government and processes of state formation by extending territorial connectivity and enhancing political legitimacy (Alder, 2014; Camprubí, 2014). This logic of territorial governance through engineering has been traced back to experimental aristocratic gardens and 'impossible' canal projects of seventeenth-century France (Mukerji, 1997; 2009) and to extensive road building by the 'infrastructural state' in late-eighteenth-century and early-nineteenth-century Britain (Guldi, 2012). Patrick Joyce (2003: 69) suggests that in Britain 'from at least 1800 civil engineering had emerged as a major, largely unacknowledged, arm of the government'. Indeed, historical research has demonstrated how engineering played a key role in the consolidation of British imperial power, facilitating control over territories, regional economies and subject populations (Dossal, 1988; Mitchell, 2002). The engineering of large buildings, roads, waterworks, ports, sewers, parks and communication systems have thus helped demonstrate what Mukerji (2003: 656, original emphasis) calls 'a *collective capacity* to dominate that has been a foundational and legitimating principle of power'. In relation to cities, engineering has been enlisted in marking out and unifying urban territory and has involved the establishment of quantifiable metrics and standards that assist in the task of administrating across heterogeneous space (Barry, 1993; Scott, 1998; Bowker and Star, 1999; Barry, 2001). As Schultz and McShane (1978: 407) observe with reference to nineteenth-century US cities, 'within their specialized functions, engineers had developed centralized agencies capable of long-range, comprehensive planning'. In their focus on problems at an urban scale and projections beyond short-term priorities, through a reliance on centralized bureaucracy, fiscal instruments and educational and professional institutions, engineers have been central to the creation of forms of municipal governance (Seely, 1982; Cosgrove, 1990; Dossal, 1991).

This work of engineering in establishing and maintaining urban government through processes of territorialization, standardization and bureaucracy has been understood as enacting impersonal control—what Mukerji (2009: 7) refers to as 'the stuff of modern state administration and technocratic government' (see also Hull, 2012). Engineering has been characterized as a technology of rule for governing subjects at a distance rather than through more direct disciplinary measures and totalizing forms of sovereignty. In relation to nineteenth-century London, Christopher Otter (2004: 63) argues that 'tentacular networks of electric wires and water mains could subtly shape and normalize conduct, without any direct human interference, save for the occasional repairman or meter reader'. In their pervasiveness and connectivity—yet mundaneness and seeming neutrality—the 'stuff' of engineering has played a central role in shifting forms of urban liberal governmentality, whereby rules of conduct are not imposed but shaped through an exercise of freedom (Barry, 1996; Joyce, 2003). Engineering systems in colonial cities, such as the large-scale gravitational water schemes that supplanted (at least in part) 'artisanal' hydraulic practices, have also helped usher in standards of normalcy, modify 'native' behaviour and foster new routines of everyday life (Broich, 2007; Kooy and Bakker, 2008).

Urbanists have shown how modernist ideals of the orderly and healthy metropolis have been at the heart of liberal projects of state making. In the latter half of the nineteenth century, for instance, engineers were at the forefront of efforts at instilling ideals of urban sanitation, cleanliness and order in rapidly industrializing Western cities through grand technological visions and modern ideals of urban integration, equity and cohesion.[2] As Graham and Marvin (2001: 44) suggest, 'the growing corps of urban engineers [from the 1850s] sought to understand the growing industrial city as a systemic "machine" that needed to be rationally organized as a unitary "thing" using the latest scientific and technological practices available'. This 'modern infrastructural ideal' gave political and ideological impetus to new water-supply projects, sewerage systems and other public works that aimed to lower disease and mortality rates, while new communication enabled modern experiences of speed and mobility. As an infrastructurally integrated, fully networked urban fantasy of the modern engineering imagination became central to understandings of progress (*cf*. Picon, 2018, this issue), ambitious and spectacular feats of extended urban engineering—large dams enabling water supply to Athens, for instance (see Kaika, 2006), or the 'improvement' projects of British India (Dossal, 1988; Chandavarkar, 2009)—became key markers and symbols of urban modernity.

Yet despite the massive transformations in urban form and everyday life—as well as the many health and material benefits that have undoubtedly derived from engineering projects—research findings have challenged the empirical accuracy and normative presumptions of an urban engineering ideal and its implied universal inclusivity and integrating effects. From insufficient water pressures for reaching the upper floors of working-class tenement housing, social biases of highway design, differentials in how engineering components are repaired and maintained to recent digital divides, there have always been socio-spatial differences in infrastructural connectivity, integration, distribution and functionality (see e.g. Winner, 1980; Dossal, 1991; Chatzis and Coutard, 2005), and perhaps particularly so in colonial settings. While this may in part be a result of the complexities involved in transferring technologies across contexts (Headrick, 1988; Gandy, 2014: 9), postcolonial theorists have pointed to how patterns of rule and relations of governance with roots in a colonial past continue to inform contemporary patterns of citizenship (Mamdani, 1996; Chatterjee, 2006). Colonial-era engineers were enlisted in materializing differential regimes of citizenship and subjecthood, articulated through the uneven infrastructural configurations that persist in postcolonial urban geographies (Chatterjee, 2006; Kooy and Bakker, 2008).

2 Merritt (2015: 9) estimates that between 1850 and 1880 in the United States, while the 'number of physicians and clergymen more than doubled and architects increased six fold, the number of civil engineers multiplied sixteen times'.

Disputes over configurations of connectivity and allocation of urban resources thus reflect social and political difference while at the same time challenging these disparities by articulating and instantiating substantive claims to urban resources (Truelove 2011; Salamanca, 2014; Björkman, 2015)—resources in whose disbursement engineers play a necessary (if sometimes unwitting) part.

Engineering and engineers have been enlisted too in the creation of new forms of globalized space as part of what Kirsch (1995) terms the 'technics of spatialization'. Engineering has been a key device in cementing the structures and relations of colonial urbanism through the technical principles and specialized knowledge involved in the construction of cantonments, ports, monuments and sanitation zones (King, 1980; Rabinow, 1989: 288). As the historian David Cannadine (2004: 172) argues, 'the imperial cities of Bombay and Calcutta, Cairo and Lagos were extraordinary monuments to British expansion and engineering'. Today's transnational city networks retain aspects of colonial relations of engineering expertise with the concentration of specialist engineer firms, activity and technology helping generate and articulate 'global cityness' (Harris, 2013). Rimmer (1991: 104), for instance, suggests that 'movements in the location and the importance of transnational engineering consultancies are faithful barometers of shifts in a city's international status and the processes of economic restructuring'. Engineers, building on their role in pioneering forms of management consultancy (Wright and Kipping, 2012), are now key players not only in state-led megaprojects, but in transnational development companies and infrastructural firms, where their expertise is central to bringing together new building forms, financial instruments, public–private partnerships, technological innovations and contracting arrangements (Rapoport, 2015). These companies are often engaged in the customized development of 'premium network spaces' (Graham and Marvin, 2001), new forms of 'iconic' architectural space and the establishment of a 'world-class' city (Harris, 2013).

Given the constitutive role of engineering in forms of urban statecraft, in articulating aspirations to globality and in various experiments of city 'worlding' (Roy and Ong, 2011), an empirical emphasis on engineering offers an entryway into probing key analytical concepts and conceptions within urban studies. These include the workings of governmental power, the production of urban space, and the location and forms of urban contestation, resistance and political claims-making. Investigating the scope and implications of urban engineering can, moreover, help challenge scholarship that locates power primarily in the institutionalized and centralized apparatus of its exercise (modern states, colonial powers, national economies). A focus on the role of engineers in processes of city making can open up an emphasis on more dispersed and polyvalent sources of power and more mundane sites of everyday interaction, encounter and control.

## Between engineering theory and practice

The portrait of the engineer laid out in the previous section tends to posit (implicitly or explicitly) a particular relationship between engineering *theory* (official regimes of knowledge classified as science, mathematics, mechanics)[3] and engineering *practice* (decision, design, action)—a relationship in which formal (generally state-sanctioned) knowledge and empowered action are theorized to conjointly articulate, embody and (re-)produce broader societal relations of authority and power (Kuhn, [1962] 1996; Foucault, [1969] 1982).[4] Yet this particular idea about the relationship between engineering theory and practice only partly reflects what a wider body of social-science research on engineers and engineering has revealed. Sociologists inspired

3 There is a significant body of scholarship in STS demonstrating the fallacy of commonly held notions of the certainty of science (see Bijker *et al*., 1987; Jasanoff *et al*., 1995).

4 This notion follows Foucault's notion of *episteme* and Kuhn's theory of *paradigm*.

by neo-Marxian critiques and Bourdieu's ideas of social field, for instance, have posited a primary and more deterministic account of technological change (see Picon, 2004). The content of engineering *theory* is described to reflect capital-driven technological innovation, while engineering *practice* is described as the enactment of this official body of knowledge, which is transmitted through officially sanctioned (accredited) channels of engineering education. This sociological attention to the content of engineering education and training of course does not necessarily problematize a Foucauldian/Kuhnian portrayal of engineering but rather makes an explicit argument about the *origins* of power (that is, technological change) and points to a particular institutional mechanism (namely, education) by means of which power knowledge operates.

Historians of engineering, however, have challenged the presumption that institutionalized knowledge somehow reflects technological change in the first place (whatever its origins). Indeed, historical attention suggests instead that changes in professional organization have had an uneven and unclear relationship to wider technological developments. On the one hand, major technological innovations in the nineteenth and early twentieth centuries were driven not by engineers but by myriad 'uncounted entrepreneurs and inventors' (Beniger, 1986: 19); on the other hand, changes in the professional organization of engineering 'do not necessarily coincide with all the episodes of accelerated scientific and industrial transformation' (Picon, 2004: 427). What we learn from European engineering history is that variations in engineering practice are more closely tied to particular socio-cultural and political contexts than to changes in the content of what may or may not be formally categorized or institutionalized as engineering theory (Vérin and Gouzévitch, 2011). What is more, the relative importance devoted to various dimensions of formal knowledge has been shown by historians to diverge significantly across contexts: French engineering curricula, for instance, have devoted (and continue to devote) significantly more attention to mathematics than Anglo-American professional training does. Also, local engineering 'traditions' are at least as decisive as any presumably 'objective' efficiency-maximizing imperative in informing engineering practice: 'whereas an Italian engineer will often privilege a solution based on a bridge', Picon writes, 'his French colleague will examine whether it is possible to cross with earth-moving' (Picon, 2004: 428).

Historians of industrial organization, for their part, have pointed out that the relationship between engineering theory and practice is often mediated by culturally informed conventions of hierarchy and authority, such that in any given organization (state or non-state), the practical priority given to one or another kind of knowledge is an expression of 'command protocols' (*cf.* Picon, 2004: 425)—whether institutionalized or otherwise—which may or may not reflect broader societal and cultural trends. The history of engineering tells us, in other words, that, first, there is no clear connection between technological change and the content of formal (state-sanctioned) engineering knowledge; secondly, that the content of what is formalized as engineering knowledge (that is, what counts as official knowledge as codified in professional training and in institutionalized protocols) not only varies significantly across socio-cultural and political contexts but is also *internally* diverse insofar as operating as per the constraints of 'official knowledge' may still offer up any number of possible approaches to any particular problem among which engineers must decide; and thirdly, that in any case we still know very little about how formalized knowledge (engineering *theory*) relates to actual engineering *practice* (decision, design, action).

In this context, some of the most exciting and suggestive thinking about engineering comes from STS, where close ethnographic research has drawn attention to the contingent and unpredictable ways in which theory and practice interact in particular contexts. Indeed, STS research has demonstrated how scientific knowledge is itself the outcome of collective activities that are run-through socio-cultural processes of meaning making (Bijker *et al.*, 1987; Latour, 1987; Lagesen and Sørensen, 2009), thus gesturing towards the spuriousness of any pre-theorized divide between engineering theory and practice in the first place. These findings from STS thus call into question the way engineers have generally been conceptualized and characterized in urban studies—as instrumentally reasoning implementers of state-backed knowledge regimes, whose technocratic interventions comprise everyday work of (re-)producing materialized structures of power in and through urban space.

Yet at the same time as these studies reveal the theory–action divide as a *boundary effec*t of engineering practice itself, we also know from historians that, however imaginary these boundary effects may be, they are also enduring and stable, and have material implications: they shape technological systems, produce hierarchical valuations of knowledge and legitimate social institutions and regulatory frameworks within which engineers operate. The theory–practice boundary effect can thus be rather 'obdurate' (Bjiker, 2007), bound up with significant socio-cultural, political and material investments. So while STS reveals the highly contingent nature of the interconnections between knowledge, action and material outcome, it has less to say about any generic relationships between, first, continuity and change in institutionalized configurations of engineering knowledge in different contexts; secondly, the relationship between institutionalized knowledge regimes and global-level technological innovations; and thirdly, actual practices of engineering.

### What is engineering in practice?

What are we are talking about when we talk about engineering? The profession of engineering is bound up with modernity's privileged domains of knowledge and knowledge production: physics, mathematics, mechanics and experimental science (Picon, 2004; Seron and Silbey, 2009; Trevelyan, 2010). In allowing for the 'modeling of physical relationships that in turn allow analysis, optimization and prediction' writes engineer-turned-academic James Adams, reflecting on his pre-university career as aerospace engineer, these things provide the 'intellectual toolkit that separates the engineer from the technician' (Adams, 1993: 42). If airplanes are not built 'extremely efficiently', Adams points out, they quite simply will not fly; it is 'impossible to escape the laws of physics—and the symbols which express those relationships—when solving these sorts of problems' (*ibid*.: 107). Adams' monograph thus demonstrates how 'the world of an engineer' is a land of trial-and-error problem solving under the often conflicting constraints and imperatives of mathematical laws, scientific theories and business imperatives. That is, while much of engineering *theory* is based on mathematics, much of the actual *work* of engineering is comprised of experimentation:[5] 'If one has no pertinent experience to draw on, and one cannot find an applicable theory',[6] Adams explains, then engineers seek to discover 'the best way' to approach a problem through a process of trial and error (*ibid*.: 150). Experimentation is at the heart of mechanical engineering, where theory is often of little help; since 'no physical law allows us to predict how long things will last before they wear out', Adams explains, it is necessary to build 'prototypes and test them to see' (*ibid*.: 45). This emphasis is also brought to bear by anthropologists Harvey and Knox (2015: 10) in their ethnographic research on road construction in Peru: 'when one pays close attention to the practices through which expertise is performed, it becomes clear that the professional skill of the engineer always requires something beyond the abstractions of technical expertise. The mathematics and the metrics are necessary but never sufficient for the realization of engineering projects'.

5 Moreover, much of the work of engineers involves the experimental testing of various theories—in the aspect of engineering known as 'development'.

6 Even in cases where some relevant theory might exist, moreover, 'often no one in the group is familiar with it' (Adams, 1993: 152). Adams recalls how he came to understand that 'not only would I never know more than a fraction of [existing engineering knowledge and theory], but I would never know that much of it even existed' (*ibid*.: 152–53).

Even in cases where some theory might exist (and is known), experimentation is still used to 'bridge the gap between the idealized world of engineering theory and the complexity of reality' (Adams, 1993: 4). Notwithstanding the rigors of theory and experimentation, in complex situations error is still likely to occur owing to the large number of assumptions, to 'accidental or erroneous omissions', and because, for one reason or another, 'designs when built do not act quite as they are supposed to' (*ibid.*: 156). This is not only because engineering has its own independent set of theories and body of knowledge (known as engineering science), but because engineering is 'inherently indeterminate', relying on 'expert knowledge that is deployed in discretionary situations with clients' (Seron and Silbey, 2009: 7).

Indeed, there is a qualitative divide separating the work of engineers from that of mathematicians, physicists and scientists. Unlike the latter, who are tasked with producing knowledge *about* the world[7] and are answerable primarily to their peers and publics in universities, academic journals and laboratories, engineers are tasked with solving practical problems *in* the world—and are answerable within a broader and more diverse environment of actors and forces: socio-political, material, temporal, financial. Because engineering is a real-time activity in the world (unlike idealized notions of laboratory science), engineers carry out their work under myriad and exceedingly complex constraints and pressures. Engineering designs must be attentive and responsive to the dictates of the market, and to whether and how anything that engineers might design (a bridge, a rocket, a semiconductor) might actually get built. 'The engineer is both a scientist and a businessman', writes Edwin T. Layton in his classic work, *The Revolt of the Engineers*: 'Engineering is a scientific profession, yet the test of the engineer's work lies not in the laboratory, but in the marketplace' (Layton, 1971: 1).

While engineers might *use* formal, theoretical knowledge in their work, engineering practice and expertise is thus not *reducible* to the straightforward application of socially privileged domains of knowledge. As Levenda's (2016) account of the 'smart grid experiment' in Austin, Texas, demonstrates, for instance, such engineering 'experiments' are at least as interested in 'market-testing' as in stated goals of exploring possibilities for reducing carbon emissions (let alone in 'socially just urban futures') (*ibid.*: 5). While markets are notoriously misbehaved when it comes to following economic laws, the unpredictability of human 'end users' poses some of the most enduring and intractable engineering challenges: 'Good engineers' attempt to design products that are 'people proof', Adams (1993: 172) notes, 'however, when viewing failures in retrospect, one is often impressed at the ingenuity with which people manage to destroy the products of technology'. Humans, in other words, often do not behave as engineering models, predictions, or experiments predict.

Given the multiple and often competing constraints and imperatives to which engineers are answerable, what exactly can engineering expertise be said to comprise? The iterative relationship between theory and practice that the work of 'good engineers' entails recalls research in human learning and expertise. In a classic study, Hubert and Stuart Dreyfus (1986, cited in Flyvbjerg, 2001) drew on an experiment carried out among American paramedics: video films were made of six persons administering cardiopulmonary resuscitation (CPR) to victims of acute heart failure. Five of the six were inexperienced trainees just learning CPR, while the sixth was a paramedic with

7 Cohen (cited in Seron and Silbey, 2009: 5) defines science as 'oriented to the production and evaluation of knowledge claims'. While mathematical relationships are the basis of the physics theories on which engineering practice draws, much of this theory has an uneasy relationship to 'science' since it is often impractical and cost-prohibitive, if not outright impossible, to carry out experiments—as per the scientific method—that would reproduce the conditions that mathematics seeks to model (the birth of the universe, for instance). Mathematical modelling, therefore, aims not at scientific proof, but at constructing mathematical models that are 'consistent with observed ... phenomena' (Adams, 1993: 42–43). This means that much of what is described as engineering theory is not, formally speaking, 'science', but rather is a set of *propositions*—theories—about how, given a set of mathematical relationships, things in the world might come together or fall apart.

long experience in emergency life-saving techniques. The films were shown to three groups of subjects: paramedics with practical experience, students being trained in this field and instructors in life-saving techniques. Each subject was asked the following question: who of the six persons shown in the films would you choose to resuscitate you if you were the victim of the accident? Among the group of experienced paramedics, 90% chose the one experienced paramedic from the films. The students chose 'correctly' in only 50% of the cases. Finally, and perhaps surprisingly, the instructors in resuscitation had poorer results than either the experienced paramedics or the students, choosing the experienced paramedic in only 30% of the cases (Flyvbjerg, 2001: 10). This means that the research subjects presumably *most* fluent in the formal rules of CPR—the instructors—were *least* able to select the experienced paramedic, whose virtuoso performance of CPR presumably did not correspond directly with the official rules.

Dreyfus and Dreyfus drew on this study to outline a five-level model of human learning (what has come to be known as the Dreyfus model of human learning): in the first three levels, a learner progresses from studying context-independent rules (say, the speed at which to shift gears when driving a car), to recognizing examples of when and where these rules are relevant or perhaps ought to be ignored, to making 'a conscious choice' among various goals and priorities (Flyvbjerg, 2001: 16). In levels four and five, however, there is a qualitative leap in the kind of knowledge enlisted in performing tasks: instead of making conscious evaluations and assessments of various rule-given alternatives, *expert* performers enlist 'spontaneous interpretation' and 'intuitive judgement' to solve problems, drawing upon embodied knowledge born of prior experience.

This qualitative gap between *competence* and *expertise*—between fluency in rules and their application on the one hand and embodied, 'spontaneous' knowledge on the other—is illustrated, for example, in Artificial Intelligence (AI) researchers' efforts to program a computer that could outwit human experts at games such as Chess or Go. The human advantage in Chess and Go, AI researchers eventually realized, lay not in the speed at which calculating rule-based probability could be calculated (what AI researchers characterize as 'brute force'), but rather in reading and interpreting the *appearance* of a game board as a whole: 'good positions look good' explains robotics researcher Demis Hassabis, whose computing system DeepMind finally bested Europe's reigning Go champion in October 2015. DeepMind tries to emulate the human trick of 'board reading' through a technology called 'deep learning' that uses enormous data sets in training a machine to 'learn' a particular skill: 'Feed enough photos of a wombat into a neural net, and it can learn to identify a wombat … Feed it enough Go moves, and it can learn to play Go' (Metz, 2016). What AI researchers realized, in other words, is what Dreyfus and Dreyfus concluded about the paramedics experiment decades ago: that analytical, rule-based rationality is a *limited* rationality, 'appropriate to the lower levels in the performance of a skill, but not to high level performance' (Flyvbjerg, 2001: 21).

While the skills allowing machines to win at Go involve sorting through a mind-bogglingly large set of possibilities, the situation still remains one of a highly structured game; by contrast, the expertise of engineering introduces at least two additional kinds of complexity: a first, which we have touched on already, is that the work of engineering is bound up with spheres of activity and interaction for which generic rules or predictive theories often do not exist. Moreover, the second kind of complexity, unlike Chess or Go in which the end goal (the 'objective function') is clear (namely, to win the game), the *ends* towards which engineers are tasked with working are often multiple, conflicting and constantly revised. Engineering expertise requires not only skills in the material world but, since engineers must navigate the myriad constraints of working with clients, this engineering expertise extends into muddier domains of economics, labour and business. And in cases where the client is a public body—say, a city government—then engineering will be bound up explicitly with the vagaries of politics too.

### Engineering urban research: stuff, distributed expertise and social imagination

Given the tangled, contingent and conflictual worlds negotiated in actual engineering practice and expertise, how can urban scholarship best seek to probe the key role for engineering and engineers in processes and dynamics of city making? In this section we highlight three analytical and methodological modes of attention that *engineering cities* brings into focus: materiality, collective expertise and social imagination.[8]

First, urban engineering cannot be explored without taking seriously the 'stuff' of cities and acknowledging ongoing encounters between human intention and material potential. Whether it is valves, plastic and pipes (Björkman, 2018, this issue), tarmac, signposts and steel (Harris, 2018, this issue), geotextile lining, conduits and concrete (Usher, 2018, this issue) or trees, slurry and tunnel-boring machines (Hillier, 2018, this issue), urban engineering is inevitably caught up with a changing articulation of matter, bodies and the built environment. Empirical attention to engineering does not simply help highlight how cities are 'materially heterogenous' (Law, 1994: 2), but reveals how material environments can have political significance and operate as discrete actors in a 'government of things' rather than simply as intermediaries (Bennett and Joyce, 2013; Lemke, 2014).

It is helpful here to recall the distinction that Bruno Latour draws between an *intermediary* and a *mediator:* while the former transports without transforming, the latter affects/effects its output (Latour, 2005: 39). The distinction between intermediary and mediator, moreover, is not fixed, but rather is a situational effect of 'black boxing': a properly functioning computer could be taken as a good case of a complicated intermediary, while a banal conversation may become a terribly complex chain of mediators in which passions, opinions and attitudes bifurcate at every turn. But if it breaks down, a computer may turn into a horrendously complex mediator (*ibid.*).

The devices, artifacts and tools of engineering similarly come into focus as either intermediaries or mediators, depending on the situation and perspective: sometimes they can appear as intermediaries, simply conveying materials or resources and thus appear to comprise a mundane technology of the 'techno-scientific state' (Carroll, 2012: 490). Yet the 'vibrancy' (Bennett, 2009) of matter can also disrupt the designs of their authors, with the stuff of engineering coming into focus as a mediator even when only asked to intermediate: geophysical phenomena in particular can frustrate the travel of engineering technology, with soil, algae and mud frequently working differently in receiving environments than in the settings (or controlled laboratory conditions) where designs may have been tested and established (Broich, 2007; Björkman, 2015). As Ken Alder points out, 'engineers work with a material world that is "thick". Bulk matters. To change the size or shape of a physical object is to transform its performance in ways that are difficult to predict' (Alder, 2014: 13). Materials such as concrete can furthermore play a central role in mediating relations of capital investment and labor, often in the process helping establish the primacy of engineering expertise (Harvey, 2010). As the architectural historian Adrian Forty suggests in his survey of concrete and culture, 'more than any other occupation, engineers have been the beneficiaries of concrete' (Forty, 2012: 240).

Secondly, while the work of engineering invariably involves acting in and on the physical and material world (and vice versa), it is equally bound up with the

8 Our threefold schema both recalls and interrogates Carroll-Burke's (2002: 76) analytical framework for theorizing the relationship between engineering, culture and politics in which he lays out 'a theoretical concept of "engineering cultures" and through that "engineering states" by employing a triangulated analysis of ideas (discursive and institutionalized), practices (embodied, temporalized and organized) and material culture (whether tools, bodies, built environment or land)'.

intersubjective work of coordination and collaboration among a great many people with diverse interests. The word 'engineer' comes from the Latin word *ingeniatorem*, which might be translated as 'someone who is ingenious at devising' (Coyle *et al.*, 2007: 145). As historian Hélène Vérin (1984) points out, engineering (particularly in its military capacity)[9] has frequently been associated with deviousness and trickery; tasked with navigating treacherous and unknowable realms, the engineer is like Ulysses, 'wandering in a strange and threatening world the dangers of which he had to conjure through tricks like the Trojan horse' (Picon, 2004: 430). But while Ulysses wandered alone, the ingenuousness of the engineer inheres not in the autonomous acts of an individually reasoning subject, but emerges through intersubjective practices of 'interaction, communication, and conflict' (*ibid.*). Indeed, empirical work such as that of Chandra Mukerji (2009: 5) on the construction of the Canal du Midi in France reveals less the heroics of individual engineers such as Pierre-Paul Riquet than the 'collective intelligence' of groups 'with both formal and vernacular expertise in land measurement, construction and hydraulics'.

As engineer-academic James Trevelyan writes, 'the foundation of engineering practice is *distributed expertise* enacted through social interactions between people: engineering relies on harnessing the knowledge, expertise and skills carried by many people, much of it implicit and unwritten knowledge' (Trevelyan, 2010: 175, emphasis added). The motivation behind Trevelyan's research lay in a paradox: when describing their work, engineers tend to reserve the term 'engineering' only for those solitary activities that are characterized as technical in nature; yet 'job-analysis' research reveals that engineers actually spend most of their working time interacting with and coordinating other people (*ibid.*: 183).

Inspired by the disjuncture between engineers' characterizations of the 'real' content of engineering (as individual reasoning and calculation), and the amount of work time devoted to various intersubjective activities dismissed by engineers as 'non-engineering' (*ibid.*), Trevelyan sets out to 'reconstruct engineering from practice', laying out a six-phase model of engineering. From the very moment that a project is conceptualized, engineering is bound up with communicative practice. The first phase of an engineering project involves an 'attempt to understand and at the same time shape clients' perceptions of their needs' (*ibid.*: 188). This work of imagining and representing some phenomenon in the world as an *engineering* problem, Trevelyan points out, is largely about 'gaining clients' and investors' trust and confidence', since money will be spent and much time will pass before the project comes to fruition and any benefits from the project are actually seen. Far from being a technical exercise, problem framing comprises the intersubjective work of forging understandings of the scope and content of the problem, including the goals of the project, and establishing social relations of trust that will allow a project to weather significant risks over the period of a project—financial, reputational and material risks—borne not only by clients, but by engineering firms and investors too.

Phases two and three are the 'problem-solving' stages of the engineering process, when engineers imagine various possible solutions to a problem as articulated and agreed upon. This creative work involves 're-arranging elements drawn from a vast memory of design fragments and piecing them together' (*ibid.*: 189) and then—drawing on data, mathematical models and previous experience—putting together a 'sensible' design that also matches 'investors' acceptance of risk and uncertainty'. This work is therefore highly fraught, since the inherent uncertainty of many dimensions of an engineering project (negotiating approvals from various regulating authorities, for instance) renders any prediction of risk highly subjective. Clients and investors

9 Geographer Peter Merriman (2005: 123) points out that engineering has been most clearly enlisted in dimensions of history 'which are intimately bound up with practices of warfare'.

thus decide whether to proceed with a project only in stage four, when detailed work plans are drawn up, tendered and contracted. Engineers actually 'perform' a project in stage five, which largely involves the informal communication and coordination that seeks to ensure that 'work is performed safely, to an agreed schedule, within an agreed budget, and within negotiated constraints such as regulatory approvals, effects on local community, and the environment' (*ibid*.). Engineering practices are thus not only materially contingent but socially contextual (Petroski, 1997: 80–81; Gandy, 2014: 24)—'a combined performance', Trevelyan (2010: 188) concludes, 'involving, among others, clients, owners, component suppliers, manufacturers, contractors, architects, planners, financiers, lawyers, local regulatory authorities, production supervisors, artisans and craftspeople, drafters, laborers, drivers, operators, maintainers and end users'. Indeed, as Law and Callon (1988: 284) point out, 'engineers were practical sociologists long before the discipline of sociology was invented'.

In the urban context, the 'distributed expertise' and 'combined performance' of engineering comprise key infrastructures of everyday urban life (see e.g. Graham and McFarlane, 2015). Attention to engineering cities thus invites attention to quotidian, itinerant and pragmatic practices as engineers improvise in unstable realms and mediate among what are often contradictory imperatives—of political machinations and rumor, and the unruliness and 'differential resistance' of diverse material life that evades direct control (Barry, 2013: 149). As Hillier's exploration (this issue) of the mechanical techniques, contractual arrangements, tunnelling locations, legal agreements and risk assessments involved in the construction of the Thames Water Ring Main highlights, 'engineering in action' does not (only) transmit but also *blocks* informational flow—whether inadvertently or otherwise.

Thirdly, the intersubjective and communicative nature of engineering knowledge and practice (and indeed of socio-technical systems more generally) means that engineering is bound up with the work of social and cultural imagination, described by Antoine Picon (this issue, p. 264) as the 'image-based systems of representation and values that are shared by various collective stakeholders concerned with infrastructure'. An empirical focus on engineering thus invites (even impels) attention to the embodied experience and day-to-day meaning-making work in everyday life that Raymond Williams (1961: 48–49) terms the 'structure of feeling': a sort of common sense 'as firm and definite as "structure" suggests, yet ... operates in the most delicate and least tangible part of our activities'. Indeed, the imagination of the engineer, as Picon (2004: 431) points out, 'is intimately linked to the system of images that prevail in the society of which he is a member. The engineer's imagination appears as a component of social imagination'. This social imagination has a dual role: on the one hand, it provides 'justification of the present state of society' and functions like 'ideology'; on the other hand, the social imagination is a form of utopianism—a fantastic 'exploration of a different and better future' (*ibid*.).

The necessity and promise of research attention to social imagination (and, for our purposes, to engineering imagination in particular) lies in the ability of imagination to illuminate and explain both *continuity* and *change*—both change in how engineering knowledge is institutionalized over time and in different contexts, as well as how technological innovation may or may not affect change in engineering knowledge and practice (either officially or otherwise). These pressing questions of continuity and change (as outlined earlier in this article) are dynamics that STS research on the contingency of the relations between knowledge, action and material outcome is unable to explain. While the institutionalized (and materialized) ideas, images, knowledge regimes and justificatory frameworks of modernist urban engineering have historically been bound up with organicist metaphors of flow (Picon, this issue), the network-flow imaginary increasingly coexists with competing paradigms bound up with digital technologies and utopian 'smart city' fantasies harboring spatio-temporalities quite different from those of network flow. It is to the shifting, contradictory and uneasy coexistence among multiple engineering imaginaries—both established and emergent—that we now turn.

### The problem of multiple ends: managerialism, audit culture and 'smart' technology

Recent decades have witnessed a distinctive change in the way cities across the globe are known and represented. International policy debates and urban planning practice have shifted attention away from a focus on practical concerns about material flows through urban space, and instead towards the valorization of the individual, responsible city dweller. Individual creativity, ingenuity and adaptability are increasingly believed to underpin the ability of a city to thrive: to run efficiently, to absorb economic or and environmental shocks, to respond optimally and rapidly to change, to hedge risk and to bounce back from myriad forms of adversity—a shift from what might be described as a 'supply city' to a 'sensitive city' (Brown, Keith and Wong, 2009; *cf*. Batley, 2004).

Modernist ideas and ideals that urban processes and circulations—of water, transport and sewage—are the work of engineers and of engineering have been increasingly sidelined by a 'management' paradigm that extends market ideologies and rationalities to questions of city governance (Walsh, 1995; Manning, 2001; McCourt and Minogue, 2001; Larner and Laurie, 2010). The management idea and ideal envisions on the one hand the supplanting of public-sector engineers by private-sector managers thought to be more efficient, and on the other hand the institutionalization of market mechanisms and logics of individual choice in the provision and allocation of urban resources (Batley, 2004; Batley and Larbi, 2004)—what Strathern (2000: 2) describes as the 'twinned precepts of economic efficiency and good practice'. In this reconfigured ideological context, city engineers are re-envisioned as individual interest maximizers who can be incentivized to improve infrastructural 'performance' through the institutionalization of 'best practices', the emulation of policy frameworks borrowed from 'model cities' (Huat, 2011; Pierre, 2011) and by rendering public officials 'accountable' to city residents—now re-envisioned as 'consumers' (Blair, 2000; Batley and Larbi, 2004; Dibben *et al*., 2004). The management idea has been cast as a 'magic-bullet' solution for cities of all shapes and sizes—a way to improve service delivery and manage fiscal crises in northern cities, as well as a remedy for the presumed 'bureaupathologies' of the global South (Dent *et al*., 2004).

In this transformed ideological context, the complexities of engineering cities—the uncodifiable, improvisational expertise of city making, maintenance and mediation that we have been describing—are obfuscated, occluded and superseded by other knowledge regimes and governance paradigms. Engineering expertise is increasingly asked to become accountable (and even take a backseat) to other forms of valorized (and more legible) urban knowledge: international benchmarks, mobile models and, increasingly, to the informatics tools, data aggregation techniques and auditing technologies through which policymakers worldwide increasingly seek to streamline and optimize urban processes. Among the most prized new forms of knowledge is the 'audit'. Based on the techniques of financial accounting, the scope and practice of auditing has been radically extended in recent decades, with society increasingly 'organized to observe itself' through the work of self-monitoring (Strathern, 2000: 3). The extension of auditing practices into the internal workings of public institutions (Munro and Mouritsen, 1997) has dramatically expanded the scope and meaning of 'governing at a distance' (Rose, 1999: 154)—by reconfiguring geographies of power, by simultaneously concentrating and dispersing locations of knowledge production, aggregation and use, and by relocating centers of urban governance and control (Townsend, 2013).

Meanwhile, the rapid expansion of information aggregation and sensing technologies into everyday urban life (particularly with the global spread of the smartphone) has fueled a veritable data revolution—making new and novel forms of urban information available to scientists and practitioners, and animating industries and university research programs devoted to the new science of 'data mining' and 'urban informatics' (Foth, 2008; Townsend, 2013; 2015). This new science of cities has in turn fueled utopian fantasies about the promises of urban modelling, prediction and possibilities for real-time intervention and flexible forms of 'just-in-time' governance. In this context, city engineers—who are after all still responsible to a large extent for cities' functioning, much of which is perhaps not *really* manageable through data aggregation technologies, individual incentives and management strategies—are nonetheless increasingly impelled to operationalize the tools and technologies of data aggregation upon which 'audit culture' (Strathern, 2000; Kipnis, 2008) insists, while also negotiating the everyday materialities and practical challenges that the work of engineering cities demands (Nelson, 2000; Batley, 2004; Björkman, 2015). The global spread of and enthusiasm for putting sensing and data aggregation technologies to work to address urban governance concerns and building 'smart cities' is increasingly matched by what Rittel and Webber (1973) described as 'wicked problems':[10] the mistake in seeking to meet the challenges of urban planning and governance using tools and techniques of predictive science, Rittel and Webber (1973: 160) point out, is not simply the inadequacy of theory or insufficient information, but rather the more fundamental problem that the 'plurality of objectives held by pluralities of politics makes it impossible to pursue unitary aims'.

### Symposium contributions

Given the extraordinary diversity of activity and expertise comprising engineering—combined with a lack of scholarly consensus on what it might mean to describe something as *urban* (let alone call something a city)—what is it that we might hope to accomplish in pulling together this collection of articles around the theme of 'engineering cities'? The proposition the symposium advances is that empirical attention to engineering cities works as a *diagnostic*—as a methodological entryway for exploring the trials and transformations of the contemporary global era, and for thinking about the place of the city (as an idea and representation, an object of knowledge, a sensory experience, a utopian project, and as a spatialized process) in these transformations and contestations.

The symposium begins with a piece by the historian of technology, Antoine Picon (this issue), which offers a conceptual framing of and provokes thinking about the role of 'social imagination' in the design and workings of urban infrastructures—an idea that emerges in various ways throughout the contributions to this collection. Picon's intervention begins with the observation that, while existing scholarship has had much to say about 'infrastructure as object or technical system, or infrastructure as a set of social behavioral patterns', we still know little about 'how these two orders of reality should be linked' (p. 263). To make sense of the relationship between these 'two orders of reality', Picon draws attention to the concept of 'social imagination'. Large-scale infrastructural projects, Picon points out, are rarely (if ever) achievements of a 'creative individual'. Rather, they are 'driven forwards by collectives and carry the mark of their imagination' (p. 265). The idea of social imagination helps account for both the stability and endurance of urban infrastructural configurations as well as how changing social imaginaries can 'hatch projects that shake up this existing order' (*ibid.*). Providing an empirical focus that, unusually for urban studies, straddles a *longue durée* of infrastructural innovation—the making of Haussmann's Paris in the nineteenth century and the contemporary rise of the smart city paradigm—Picon's account unsettles received notions about a naturalized 'network-flow' imaginary against which

10 Rittel and Webber (1973) coined the term 'wicked problems' a generation ago in their unheeded critique of an earlier era of predictive science.

much empirical research on urban infrastructures is read.[11] Calling attention instead to the nature of infrastructure as an 'imaginary-practical entity' (p. 272), Picon points out that infrastructural imaginaries have both ideological and utopian dimensions, and that in this context, city engineers 'do politics while pretending only to be serving objective purposes' (p. 269).

The subsequent four articles draw on Picon's conceptualizations and propositions regarding engineering and infrastructural imaginaries to provide in-depth engagement with detailed and situated empirical cases of urban engineering 'in action' over the past 30 years. The articles develop more ethnographic modes of research, in particular excavating the 'material politics' of engineering practice and generating new insights into myriad and often competing forms of 'official' knowledge and expertise vying for legitimacy, primacy and authority over urban space. This disrupts a tendency in much work on large-scale state schemes to conceive structures of power as somewhat monolithic and unitary, working singularly (if perhaps ineffectually) to render unruly places and people knowable, legible and governable (Scott, 1998). Engineers' ambiguous status as 'anti-political' technicians yet still political actors means they do not fit neatly within received conceptualizations of power and authority, while the everyday challenges they face often reveal some of the inherent contradictions of state infrastructural regimes.

Lisa Björkman's article (this issue) explores the dueling imaginaries at play in Mumbai's water distribution infrastructures, demonstrating how material and political conflicts and contradictions fueled by these dueling infrastructural idioms are mediated by the everyday work and increasingly fraught relations between two urban figures: municipal water engineers and neighborhood 'plumbers'. Analytical and empirical exploration of the material-hydraulic and ideational-imaginary dimensions of infrastructural engineering thus calls into question some received understandings of the relationship between institutionalized knowledge, material authority and political mediation. Andrew Harris's article (this issue) stays in Mumbai but rather than delve into the conflicts over underground infrastructure looks to engineered structures above ground: namely, recently constructed elevated roads and walkways. These, he argues, have been implicated in elite efforts at reshaping the everyday flows, socio-material configurations and spatial relations of urban life in Mumbai. Through a focus on the practices, procedures and visions associated with urban engineering, he suggests, new analytical and political insights can be developed around the production and negotiation of urban 'formality'.

Highlighting the role of engineers in processes of city making offers significant analytical potential for developing neo-Foucauldian (Foucault *et al*., 1991) work on 'governmentality' that investigates 'deliberations, strategies, tactics and devices employed by authorities for making up and acting upon a population and its constituents' (Rose, 1996: 328). Indeed, as Foucault (1989: 339) himself observed, 'it was not architects but engineers and builders of bridges, roads, viaducts, railways ... those are the people who thought out space'. This engagement between engineering and governmentality is probed by Mark Usher's account (this issue) of the shifting regime of governance techniques brought to bear on Singapore's drainage infrastructure. Usher documents how the imperatives of managing a public health crisis destabilized earlier top-down systems to control and contain water within concretized channels, leading to an intra-state conflict between engineers and administrators. By drawing on a lesser-known strand of Foucauldian analytics that takes the engineer and the technician as key figures in the production of 'the milieu', Usher chronicles the emergence of a new regime of

11 Picon's account also disrupts common arguments in critical urbanism around the destructive role of Haussmannization: it 'did not seek to destroy historical Paris, even if it did make whole swathes of it disappear. Rather, it sought to glorify its heritage by uncluttering its major monuments and placing them within circulatory plans intended to render the city both more spectacular and more efficient' (this issue, p. 268).

citizen 'responsibilization' in the governance of Singapore's drainage infrastructures. He shows how the specificities of a material-ecological crisis led to the reconfiguration of drainage governance, while leaving intact the centralized institutional configurations governing other metabolic processes such as water and sewerage. Usher's account, like Harris's on the role of flyovers and skywalks in shaping spatial imaginations and codes of conduct in Mumbai, not only emphasizes engineering's capacity to isolate and control a field of relations—while being understood as strategically beyond politics—but also complicates singular understandings of the relationship between governance, infrastructure and environment. Their research points to how crucial it is to recognize historically specific constellations in shaping the role of engineering in relations of power and dominance, and how postcolonial metropolises such as Singapore and Mumbai need to be understood as characterized by multiple modes of governmentality (Gandy, 2014).

Joseph Hillier's concluding contribution (this issue), like Björkman's, also explores efforts at introducing a new water network system to supersede older pipes. His analysis similarly disrupts standard stories of the relationship between urban infrastructure, state authority and the wider public realm. Hillier details how a conflict of priorities between public-sector managers and contracted technicians (the former accountable to a taxpaying public and the latter to private shareholders) resulted in a devastating accident during the construction of London's Water Ring Main during the 1980s. The subsequent privatization of the municipal utility, Hillier argues, enabled a new commercial cooperation wherein 'rather than negotiating around what work had been agreed for one contract price', managers and miners were united in a 'partnership' (p. 349) around shared goals of profit, efficiency and risk mitigation. Hillier's account contests the normative and empirical basis for what has been called the 'participatory turn' (Saurugger, 2010) in global policy discourse, provocatively concluding with the suggestion that perhaps 'engineering practice' is 'arguably not conducive' to such idealized (and perhaps ideological) institutions of 'accountability' and 'participation' (p. 346). This opens up tricky questions about the 'unenviable position' in which this places engineers, given their negotiations not only with complex geophysical and technical realms but multifaceted, long-standing democratic issues.

As all the contributions to this symposium demonstrate, city engineers can become key (if somewhat unlikely and even unwitting) political actors, making decisions not only regarding technical matters but becoming increasingly responsible for adjudicating matters around citizenship rights and entitlements too. Yet at the same time we also see across this symposium's contributions that notwithstanding these kinds of ideological and technological shifts—and the frequent complicity of engineers and engineering in processes of urban fracturing and fragmentation—the size and scale of many engineering projects, networks and visions still requires collective investment and close engagement with ideas of non-appropriable 'public' goods and networked services in the urban political arena (Kirkpatrick and Smith, 2011). It is the *engineer* who is tasked with mediating the conflicts and contradictions among these multiple and contesting urban imaginaries: the incompatible ends, the competing notions of causality, the divergent ways of knowing and representing the city. It is the 'spontaneous interpretation' (Flyvbjerg, 2001), 'distributed expertise' (Trevelyan, 2010), 'foundational craftiness' (Harvey and Knox, 2015: 9) and 'ingenuity in devising' (Coyle *et al*., 2007) what comprises 'good engineering' (Adams, 1993) that are brought to bear in managing, reconciling or resolving these urban conflicts. This work of mediation is the work of engineering cities.

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