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Urban infrastructure and development

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Introduction

Over the last decades there has been a revival of interest in understanding, analysing and theorising infrastructures. In Stephen Graham's (2000) words, 'infrastructure networks are being reproblematized' (p. 185). This has come along with establishing a closer relationship across social and technical disciplines and fields.

This working paper provides a selective and stylised review of the key and contemporary urban infrastructure debates. The paper's purpose cuts across two main objectives: first, to establish a point of departure and conceptual framework for the

British Academy GCRF Cities & Infrastructure project ‘Governing Infrastructure Interfaces’ led by LSE Cities, the African Centre for Cities and Addis Ababa University; and second, to explore common ground and fault lines between key disciplines involved in this project and to identify new interdisciplinary connections between technocratic and policy-oriented work on the one hand and critical, political perspectives on the other.

This working paper is divided into three parts. Part one explores dominant ‘infrastructure ideals’ that have shaped infrastructure discourses and policy over decades. Each idea has both material and institutional arrangements that underpin it. These ideals have shaped policy and thinking over time. Part two explores the tension between technical readings of urban infrastructure and social/political readings of urban infrastructure. As we show, both the technical readings and the social/political readings have struggled to engage with one another in productive ways. In the conclusion, we draw together the technical and the social/political reading, arguing for an approach that can grapple productively and propositionally with both. In addition, we argue that such an approach should be grounded in place and attentive to the emergent disruptive trends on the horizon.

Development and infrastructural ideals

There is no uniform or uncontested definition of urban infrastructure. Some definitions focus on the ‘hard’ utilities and the material networks that underpin their provision (Leipziger, Fay et al. 2003, Estache and Fay 2009). Other definitions include the people, practices, discourses and imaginaries that shape urban services (Amin and Thrift 2017). Regardless, there is a shared understanding that urban infrastructure is a system through which urban services, of various kinds, are provided.

Over time, there have been many perspectives on what the fundamental paradigm or ideal for developing infrastructure should be. Several of these ideals have had staying power, gaining traction among practitioners, academics, governments and multilateral organisations. These ideals are primarily about approaches to physical urban infrastructure systems. As a starting point for the discussion to follow, this section considers four broad infrastructural ideals that have emerged at different times historically and which continue to inform our aspirations, debates and political actions today. These include: universal networked access, connecting competitive space, ecological modernisation and new self-sufficiency. We briefly review them in this section.

Universal access

The ideal of universal access forms also a key part of the international development discourse. For example, ensuring basic access to infrastructure services featured centrally as part of the Millennium Development Goals and the more recent Sustainable Development Goals (Revi and Rosenzweig 2013). Universal access to infrastructure services is an objective, as Leipziger et al. (2003) remark, that may be easier to aim for than universal wealth.

Part of the developmental discourse of universal access hinges on public economics. The ideal of universal access is linked to a particular concern that is seen to have a public cost (i.e. externality). For example, failure to ensure access could result in spread of diseases, high death rates, poor health and the risk of social unrest (Boyer 1986). Wider concerns about societal well-being, a healthy labour force and economic productivity further strengthened the case for universal access (Revi and Rosenzweig 2013). These can be seen as ‘public benefit’ or ‘public good’ arguments. Clarke and Wallsten (2002) argue that access to infrastructure services are seen as merit goods that society normatively believes should be available to everyone.

Importantly, whether approaching infrastructure access as a right or a development tool (or both), the ideal of universal access requires determining a definition of ‘access’ and baselines to compare progress against. Most countries stipulate specific infrastructure access targets as public policy goals (Clarke and Wallsten 2002). In the case of water, for example, access to five litres of clean water and about 20 litres for sanitation and hygiene may express such a minimum level (Gleick 1998). For electricity, universality may be associated with stable, reliable, adequate and affordable supplies to all consumers (Tully 2006). Specifying universal access for other infrastructure services may be more difficult, as recent debates on transport, ICT and internet availability have shown (Gillett 2000, Estache and Fay 2009, Klimaszewski and Nyce 2009). Overall, access to infrastructure services in techno-policy work is defined in terms of geography (the distance to access services); affordability (Lee and Floris 2003, Banerjee, Wodon et al. 2008); level of service/carrying capacity (Banerjee, Wodon et al. 2008) and infrastructure literacy (Gillett 2000).

Dovetailing arguments around the scaled provision of public goods (Murthy 2013, Paget-Seekins and Tironi 2016), the Keynesian development model (Graham and Marvin 2001) and monopolistic (public and private) services (Graham 2000, Clarke and Wallsten 2002), universal access was the official infrastructure doxa of modernism, comprehensive planning and the mid-20th century era of public utility monopolies in the West (Coutard 2002). By contrast, universal access was deliberately ignored as part of the development of colonial cities, such as in African cities, where urban services were only provided in select settlements (Graham and Marvin 2001). However, it is important to note that the ideal of universal access to networked urban infrastructure is not necessarily aligned with specific political economy regimes. Historically at least, different political regimes ranging from the developmental to the liberal state have all advanced as well as struggled with addressing universal access and developing large-scale infrastructure projects to support this (Clarke and Wallsten 2002, Coutard 2002).

In contemporary urban debates, universal access underpins notions of inclusive urbanism (Marvin and Guy 2016) and the right to the city (Harvey 2008, UN Habitat 2009, UN 2016). It also features in the New Urban Agenda. In an urban context, it has also been linked to urban social movements and rights-claiming (Attoh 2011), the fair city (Parnell 2016), public ownership, re-municipalisation of urban utilities (Becker, Beveridge et al. 2015) and the practice of 'commoning' – the creation of public value beyond the logic of commodification (Harvey 2012). In addition, universal access is often associated with an undifferentiated level of investment, for example between urban and peri-urban areas, or between wealthy and poor areas in cities. While there has undeniably been huge progress made in basic access to services globally (and in particular in Africa), this approach has also enabled spatial decentralisation, suburbanisation and the de-densification of cities and urban areas, which has had a range of negative impacts (Graham and Marvin 2001).

Connecting competitive space

'Connecting competitive space' is an infrastructural ideal that is essentially concerned with economic growth, productivity and the effective deployment of scarce resources. It follows the logic of 'strengthening strengths', advocating for prioritising infrastructure investments where they can have the most impact on growth and economic development (in other words, where there is already agglomerative potential). This requires concentrating high levels of investment; practically it means investment in fewer urban environments with the greatest potential for scale economies and leveraging of investments.

The ideal of developing competitive spaces accepts an uneven distribution of infrastructural developments (Peck 1996, Jessop 1998). As the World Bank (2009) put it in its World Development Report, 'the world is not flat' (p. 8), not only accepting that economic activities are becoming more concentrated but also implicitly endorsing corresponding infrastructure policy. In stark contrast to universal access, this ideal focuses on infrastructural alignment geared toward economic productivity. It is about strategic investments that leverage the power of urban agglomeration (in particular its diverse and uneven nature) (Lall, Henderson et al. 2017).

The ideal of connecting competitive space follows the logic of urbanisation that strengthens and prioritises higher-density growth poles, accelerating economic growth and societal well-being in territorially more confined areas (Collier 2016, Collier and Venables 2016). Essentially this follows the logic of modernisation theory (Bernstein 1971); infrastructure development initially focuses on critical cities and over time comes to include other urban areas and larger rural territories (Friedmann 1967).

An approach focused on developing competitive cities and spaces thus advocates for intentional but temporal inequalities of infrastructure access, assuming that these will be mitigated over time (Graham and Marvin 2001) – a form of trickle-down urbanism – aligned with what the World Bank (2009) refers to as accepting diverging living standards prior to convergence. Connecting competitive space is centrally concerned about the efficiency in delivering infrastructure services and the maximisation of investments.

The recent report Africa's Cities: Opening Doors to the World (2017) is a good example of this argument in the context of urban Africa. In this report, the World Bank argues that the endogenous and exogenous value cities potentially have is being neither created nor marshalled for effective urban development in urban Africa. They call for local, regional and international connectivity. Connectivity enables more productive urban spaces (through scale and specialisation). This includes developing and deepening connectivity between households and firms, among firms and between firms and international markets. The key to this connectivity is to support dense development and infrastructure investment (such as transport, ICT and other networked services). Importantly, connectivity lowers costs (of transport) and increases markets (IGC, 2016). Connectivity, and by extension urban competitiveness, must be achieved through two interlocked and mutually dependent processes: urban densification and selective infrastructure investment.

This focus on efficiency, productivity and leveraging infrastructural investments also serves as a central reference for fundamental critiques of connecting competitive space with its risk of compromising universal access for disadvantaged populations in cities and rural households (Clarke and Wallsten 2002). It is usually argued that the efficiency logic further exacerbates the already considerable disparities of infrastructure access between large cities, towns and villages (Lee and Floris 2003).

The concept of 'splintering urbanism' has been used to describe the process of breaking up the urban fabric through uneven provision and concentrated investments (Graham and Marvin 2001). Exclusive areas in cities are equipped with new or retrofitted infrastructures to enhance their global economic competitiveness and connectivity (Parnell 2016). High-speed rail terminals, hub airports, global logistics centres and ultra-high-capacity fibre-optic cable access are part of the infrastructure inventory of such spaces. The areas outside of these zones, nodes and corridors are left to fend for themselves, often receiving minimal, informal and substandard, and often very costly, infrastructure (Swilling 2011).

The ideal of connecting competitive space is also exposed to considerable criticism arguing that it represents a departure from infrastructure as public good and social justice (Graham 2000, Coutard 2002). Socially regressive consequences of privatisation and competition in infrastructure utilities may result from 'cream skimming' or 'cherry-picking' (serving the most profitable consumers and areas) (Murthy 2013), eliminating cross-subsidies and leading to price increases (Clarke and Wallsten 2002). At the same time, some commentators have challenged the assumption that the unbundling of networked infrastructure utilities leads to greater socio-spatial disparities in access to infrastructure services, particularly in contexts where the ideal of universal access has been equally elusive (Coutard 2002). We pick this argument up again later in the conversation on the post-networked city.

Ecological modernisation

A distinctively different infrastructural ideal from the previous two, both ultimately focusing on socio-economic welfare, this considers instead the global environmental crisis as its point of departure. For the purpose of this overview, we regard this ideal as being aligned with the wider notion of 'ecological modernisation' and 'infrastructure transitions'. These concepts emerged during the 1980s and 1990s, and aim to overcome both the radical environmental movements of the 1970s and the central importance of using infrastructure to craft for sustainable ecological urban futures (Hajer 1995, Geels 2012, Bulkeley, Castán Broto et al. 2014, Silver and Marvin 2016).

A central tenet of this ideal is the reframing of the environment as a public good and resource rather than a free good, essentially stopping the externalisation of costs to the environment caused by the existing infrastructural and service delivery regimes (Hajer 1995). Critical analysis of the flows and consumption of natural resources alongside ecological degradation has repeatedly identified infrastructure production and operation as a fundamental space for environmental transitions (Melosi and Hanley 2000, Guy, Marvin et al. 2001, Monstadt 2009, Bulkeley, Broto et al. 2010). Increasingly, urban infrastructure is presented as a critical part of broader ecological modernisation and transition. This includes, for example, developing infrastructure that reduces carbon emissions, supports 'ecosystem services' and reduces the degradation of the natural environment.

Ecological modernisation echoes the positive, utopian position of modernism that suggests that deliberate change, in this case towards more sustainable infrastructures, is not only feasible but also highly desirable. It shares with related concepts such as green growth (OECD 2011, UNEP 2011) and a new climate economy (GCEC 2014) the fundamental assumption that economic prosperity and environmental protection can be complementary. Increasingly, the underpinning pursuit of decoupling socio-economic development and environmental degradation has been linked to risks and opportunities of urbanisation and urban change (Suzuki, Dastur et al. 2010, Rode, Burdett et al. 2011, Rode, Floater et al. 2013, Floater, Rode et al. 2014).

In terms of infrastructure development, ecological modernisation implies a central commitment to infrastructure systems, above all energy and transport, enabling the building of a green economy. In the energy sector, this cuts across renewable energy generation, smart distribution systems and energy storage. In transport, public and active transport infrastructures are the most relevant ones, increasingly complemented by electrification and telecommunication infrastructure impacting on the entire transport ecosystem. Furthermore, infrastructures of ecological modernisation are increasingly interconnected, allowing for energy and resource efficiencies generated at new interfaces and nexuses between, for example, energy and transport, transport and urban form, buildings and energy and water and transport (Belaieff, Moy et al. 2007, GIZ and ICLEI 2014). More recently, and typically under the smart cities banner, some of the ideas related to integrating infrastructure systems have also been connected to the enabling opportunities of digitalisation (Batty, Axhausen et al. 2012). Ecological modernisation thus implies the provision of a new economic impulse that can unleash a new innovation cycle as theorised by Schumpeter (Jänicke and Lindemann 2010) and lead to a new energy-industrial revolution (Stern and Rydge 2012).

The transitions literature is particularly attentive to the challenges around changing infrastructure pathways. There is a twofold concern in relation to the current and unsustainable infrastructures: on the one hand the risk of lock-in, whereby they determine future development and behaviour over a long period of time (Stern and Zenghelis 2018) and on the other that their sunk costs present investors with considerable financial losses if they become eventually obsolescent, stranded assets (Jakob and Hilaire 2015). Ecological modernisation also recognises that infrastructure services today are oversupplying and underpricing resources such as water, energy and transport with damaging effects for the environment (Murthy 2013).

An important consideration of ecological modernisation is institutional reforms that create the enabling framework for ecological/infrastructural transitions, in turn not only considering the physical problem of our ecological crisis but also the social conflicts that underpin it (Hajer 1995). In this context, ideas such as integrated transport authorities, feed-in tariffs, re-municipalisation of infrastructure utilities or citizens' energy cooperatives are exemplary cases for such reforms (Hajer and Huitzing 2012, Becker, Beveridge et al. 2015, Rode 2018). At the same time, it assumes that existing political regimes and economies are able to 'internalize the care for the environment' and reframe it as a 'management problem' (Hajer 1995). In summary, the role of infrastructure for ecological modernisation is as a central policy tool to proactively support environmental transitions and a break with business-as-usual development.

New self-sufficiency and post-networked infrastructure

The fourth and final infrastructural ideal we identified for this overview links to revived aspirations to local self-sufficiency and a post-networked urban infrastructure (Coutard and Rutherford 2015).

New self-sufficiency implies replacing the long-term objective of access to networked services with permanent rather than temporary forms of off-grid, small-scale and at times informal alternatives. New self-sufficiency suggests a rescaling of spheres of collective, citywide service provision, to individual- and community-scale infrastructural actions. It may therefore imply a considerable degree of sharing local service access points (Banerjee, Wodon et al. 2008) (water, electricity, toilets), hyper-individualised off-grid solutions and the establishment of local, micro-grids that are not connected to a wider system.

The ideal of new self-sufficiency has been taken up most enthusiastically by two groups. On the one hand, those who are deeply sceptical of centralised (and state-led) systems have opted for the development of off-grid systems that enable access irrespective of the functioning of the citywide system. On the other hand, new self-sufficiency has critiqued the networked city as an imposed ideal, out of touch with the realities of developing cities. Within this Southern Urban Theory (a sub-strand of urban theory concerned with 'southern cities'), the post-networked city is both an explicit critique and an extension of the concept of splintering urbanism. Arguments for the legitimacy of the 'post-networked city' undermine the 'modern infrastructure ideal' from which also the splintered urbanism debates depart (Pieterse 2014, Coutard and Rutherford 2015). This work argues that hybrid and heterogeneous infrastructure creates new pathways for access and city-making.

In line with thinking on the post-networked system, Simone (2004) discusses 'people as infrastructure', celebrating the ways in which people use their bodies and labour to fill the gaps of incomplete systems of provision and maintenance (Graham and Thrift 2007, De Boeck 2013). The result is a blurring of the boundaries between people and infrastructure, the human and the non-human. 'People as infrastructure' fits within of a larger body of work on incrementalism, informality and prefigurative infrastructure arrangements (Pieterse 2008). For example, Silver (2014) discusses 'material improvising' in Accra, whereby people access electricity networks in all manner of incremental and informal ways. Simone (2008) discusses the 'politics of the possible' in Phnom Penh. Pieterse (2008) writes on 'radical incrementalism' as a mode of urban change and practice. De Boeck and Amin explore the 'absence-presence' of urban infrastructure (De Boeck 2013, Amin 2014). This work holds a unique sort of optimism, one which positions developing (and particularly African) cities not as the passive sites of neoliberal destruction, but as sites of imagination and experiments, perpetual becoming, radical revision and post-networkedness (Simone 2008).

Practically, the most common forms of infrastructure services beyond grid connectivity are respectively water and sanitation solutions. For sanitation, these include ventilated improved pit (VIP), compost, chemical, concrete slab and cover (SanPlat) pit toilets, as well as septic tanks. Banerjee (2008) refers to these as 'viable substitutes for networked services' (p. x). While less common, new self-sufficiency for cooking solutions may replace non-renewable solid fuels such as wood and charcoal with liquid fuels (potentially generated through renewable sources) and for lighting could replace candles and kerosene with renewable electricity. Smaller electrical networks are arguably the most innovative area of new self-sufficiency, enabled by a new decentralised micro-generation of electricity that is operating independently from the main utility grid. These forms of electricity production and distribution can come along with considerable cost savings, supporting affordability and more rapid deployment. Some commentators have also linked self-sufficiency to political empowerment, which is evident, for example, in the literature of the off-grid movement (Rosen 2008).

The risk of relying on self-sufficiency is maybe most obvious in instances when local demand exceeds what can be supplied locally without networked infrastructure. In such cases, providing for additional services can be prohibitively expensive if not impossible. For example, supplying water to areas not connected to the main water network and where local sources are insufficient involves high transport costs and the involvement of many intermediaries is driving up costs even further. As a result, prices can easily exceed water prices charged by utilities by a factor of ten to twenty (Murthy 2013). Sustained off-grid services, particularly in an urban context, may be most difficult to maintain for telecommunication.

The literature on new self-sufficiency, while primarily concerned with the dislodging of the centralised nature of infrastructure provision, increasingly overlaps with the environmental debates over infrastructure provision. Since the early 1980s, environmentalism has frequently revisited the general idea of a self-reliant city (Morris 1990, Shuman 2013). Through building local economies, increasing the use of local natural resources and minimising waste flows so they can be absorbed by ecosystems of the immediate urban hinterland, the self-reliant city addresses the city's problems from within and focuses on a city's relationship with its bioregion. Within this bioregion, the integration of nature and settlements is prioritised over the conventional urban conversions replacing natural with artificial environments (Haughton 1997). The self-reliant city comes closest to Girardet's concept of a circular urban metabolism (Girardet 2004) and could be considered as the radical expansion of hyper-local access combined with greater local self-sufficiency.

Summary

To conclude, what all these (stylised) infrastructural ideals share is the need for more and better infrastructure; they differ in relation to their core priorities (for example, access vs growth), with corollary implications for the type of infrastructure that is advocated for.

All four infrastructural ideals acknowledge that infrastructure and services are powerful tools for shaping cities. Decisions about investments are never only technical – they extend into and shape social and political domains as well. These choices also shape how infrastructure is understood, as a right, a commodity or an investment. In this way, the ideals point to the powerful effect of infrastructure. From 'celebrated icons of modernity' (Graham and Marvin 2001, p44) to artefacts of an ecological age, Parnell (2016) links aspirations of infrastructural ideals to 'establishing utopia in an urban world' (p. 122). There are different dreams about future aspirations, justified from various perspectives.

In an actual policy-making context, the four infrastructural ideals are rarely pursued in isolation from each other and most infrastructural developments on the ground are the results of differently weighted priorities in relation to each of the ideals above. However, limited resources mean that these ideals cannot be pursued equally and all at once. They all have costs, in terms of budget, resources and capacity, which, in most urban contexts, require difficult trade-offs. Moving beyond an understanding of urban infrastructure based on ideals that drive actual infrastructure developments, the following section focuses on different readings on urban infrastructure.

Readings on urban infrastructure

There is a wide body of contemporary literature on urban infrastructure and relevant works can be grouped in many ways, for example by sectors such as water, energy, transport, communication and waste. They can also be bundled by disciplines ranging from economics and engineering to geography and anthropology. For the purposes of this working paper, we have grouped these works into two main 'camps' largely based on a discipline's explicit intention, i.e. what respective work on infrastructure aims to do:

- **Technical readings:** are explicitly concerned with the technical aspects of infrastructure. The aim is to objectively inform policy or practices related to that infrastructure system. This could be termed a technicist, techno-policy or techno-managerial approach to infrastructure. It tends to draw on disciplines such as engineering and economics.
- **Social and political readings:** use studies of infrastructure as a lens to explore social and political phenomena and challenges. While equally concerned with the operations of infrastructure, the intention is to open the 'black box' of infrastructure, expose its inner workings and reflect critically on the implications. It tends to draw on disciplines such as anthropology, geography, political science and history.

In this section, we outline the contemporary debates in each of these infrastructure camps. This is not a comprehensive review of infrastructure debates and perspectives; instead it is a stylised review of the major thrusts within the relevant perspectives.

Techno-policy work

This section first reviews the important aspects of the techno-policy work on urban infrastructure. It provides a basic vocabulary for how urban infrastructure is understood within the technical policy debates. What makes techno-policy work different from the critical readings of urban infrastructure that are expressed in section 2.2 is its focus on:

- Providing an objective analysis based on 'hard' facts.
- Quantitative analysis that provides insights in aggregate terms.
- Reliance on technical skill sets that are very particular to the infrastructure in question (i.e. water tariff design, road network).
- Explicit intention to shape policy and practice through problem identification and the development of pragmatic solutions.
- The underlying assumption that there is scarcity and, as a result, there is a need for prioritisation.

Much techno-policy work on infrastructure, particularly in Africa, departs from recognising considerable gaps in: the infrastructure that is needed, the financing that underpins it and the capacity that would be needed to roll it out. These gaps can be aggregated in various ways, for example between capital and operating costs (Paulais 2012), or by sector (for example, for transport, water, energy etc.). Above all, such work focuses on the insufficient stocks of infrastructure that in turn limit the flows of associated services and the potential for development (Estache and Fay 2009).

The techno-policy debates on urban infrastructure tend to be led by two disciplines: engineering/planning and economics/finance. There are, of course, many trained practitioners in these fields who are additionally concerned with the sorts of social and political issues that we pick up on in Section 2.2. This section does not seek to belittle the contribution of interdisciplinary thinking to the debates. Instead we seek to highlight what each of these important disciplines does add to the infrastructure debates, and the tools and methods that they bring to the table.

Infrastructure engineering and planning

Over centuries, engineering has maintained its dominant role among professional groups informing the planning and design of infrastructure projects. This has not changed even after decades of increasing multidisciplinary and multi-sectoral interest in infrastructure systems. It is thus critically important to better understand how engineering relates to infrastructure systems and how it approaches infrastructure planning. Van der Heijden (1996) identifies five key characteristics of classical engineering approaches: a mono-disciplinary approach, a limited framework of technical problem definition, a technocratic view of decision-making processes, an assumption of transparent decision-making and an assumption of one decision-maker at the top of a hierarchical structure.

Above all, engineering is deeply embedded within a positivistic worldview of a 'homo faber' who is able to control environmental and social conditions with the use of tools. This perspective operates along a linear trajectory departing from problem definition and concluding with solutions. Engineering's solutionism is characterised by a bounded rationality that sets the perimeter for a detailed and mostly quantitative problem analysis based on measurable, numerical data. In other words, engineering operates with a relatively clear boundary between variables it considers (usually within its core disciplines and related to physical and operational aspects of infrastructure) and those not considered part of its remit (above all societal and political issues) (Perez and Ardaman 1988). As a result, not only does narrow technical problem definition prevail but an application of frameworks and methodologies most common within engineering disciplines dominates.

Several conventional characteristics of engineering are helpful to unpack further: first, engineering conventionally understands itself as the application of natural sciences knowledge – or as the science of artefacts as opposed to the science of nature (Poser 1998). In his reflections on technology as applied science, Bunge (1966) differentiates between an investigator 'who searcher for a new law of nature and the investigator who applies known laws to the design of a useful gadget' (p. 330). The latter relates to the approach of an engineer who does 'not want to get better and deeper knowledge, but better ends' (Poser 1998, p5).

Second, engineering has an ambivalent relationship with context. On the one hand, engineers have to design technological artefacts that need to respond to local conditions. This is particularly the case for infrastructure systems and in instances where technology has to engage with unique conditions. Thus, universality and truth matters less to engineering than it does to science, leaving an engineer closer to 'the intellectual task of the humanities… namely, to interpret a given situation in its uniqueness' (Poser 1998, p11).

On the other hand, engineering has a tendency to reduce the level of complexity it needs to engage with in order to more confidently advance with proposing solutions. A particular tendency is to translate broader socio-technical interrelationship to more simple technical engineering problems (Heijden 1996). As a result, infrastructure systems are usually developed as 'closed systems' with considerable separation from contextual factors and uncertainties over longer time periods (Dimitriou, Ward et al. 2013).

Third, engineering is pursuing a form of optimisation based on the identified variables, problems and alternative solutions. By definition, this optimisation requires a manageable and therefore limited number of variables and factors. The identification of 'optimal solutions' is again helped by numerical tools and modelling exercises that further foreground quantifiable issues and concerns.

In terms of the planning and operational logics of engineering, classical processes rely on logical sequencing. Van der Heijden (1996) identifies seven main steps:

1. Specification of the problem and criteria for solutions;
2. Developing alternative options for problem-solving;
3. Systematic evaluation of the impacts of these options;
4. Elaboration of the related implementation procedures;
5. Choosing the best solution;
6. Implementation;
7. Ex-post evaluation.

Predefined steps in infrastructure engineering therefore lock in decisions at various stages, considerably reducing the spectrum of adjustments from each implementation level to the next. Dimitriou et al. (2013) highlight the importance of deciding the point of 'time freeze' – the moment at which the main aspects of infrastructural design are agreed. In terms of assessments and evaluation as part of infrastructure engineering, cost-benefit analysis remains the most common approach. Similarly, the three core concerns of the 'iron triangle' of project management: time, cost and output i.e. the level of delivery according to specification (Weaver 2007) are prominent features of infrastructure engineering projects.

For the governance of infrastructure projects, conventional engineering approaches essentially assume top-down decision-making processes are part of hierarchical administrative structures. Van der Heijden (1996) stresses the degree to which this view privileges the needs and criteria of the highest level of the decision-making pyramid – for larger infrastructure projects, usually the national government. As a result, there is a risk of neglecting local government and civil society. He also stresses an assumption in terms of predictability and uniformity of behaviours at each hierarchy level.

In sum, engineering approaches with their standardised norms, procedures and technical codes/manuals struggle to incorporate a fuller bandwidth of 'solutions' that may exceed disciplinary and sectoral boundaries, to incorporate contextual conditions, to connect with the politics of infrastructure projects that can supersede technical priorities, to accept various socio-technical uncertainties and to communicate their rationality to non-technical audiences.

Infrastructure economics and finance

A further prominent strand of techno-policy work has emerged through economics and the growing sub-field of spatial economics and public economics. Economics is concerned with how resources are allocated in a context of scarcity. This differs from engineering as the attention is less focused on the physical infrastructure, and more on the economic and financial implications at various scales.

Underpinning most economic work on urban infrastructure is the argument that particular services are 'public goods' that require some level of state investment or coordination to optimally provide. Within contemporary economic thought, there are many reasons why public goods should be provided, including market failure, natural monopolies and public benefit.

How these should be provided – what sorts of infrastructure, the location, price and by what sort of institution – becomes the object of complex maximisation and cost-benefit analysis (Estache and Fay 2009). Underpinning most of these considerations is the central objective of advancing economic development, as economic development is seen to be the driver of other forms of development (for example, social development) (Agénor and Moreno-Dodson 2006).

There is a clear correlation between economic growth and infrastructure development noticeable across the income spectrum of countries. Importantly, infrastructure effects on growth are assumed to be higher in lower-income countries (Estache and Fay 2009); such effects have also been established for OECD countries (Romp and De Haan 2007). It is in the first context in which infrastructure development has been linked to modernisation theory, import substitution industrialisation (Graham and Marvin 2001) and processes of structural transformation (Cohen 2006).

In order to identify the optimum level of infrastructure provision, economists have, for example, worked with the rate of return on infrastructure. Alternatives include the above-mentioned empirical relationship between wealth levels and infrastructure service demand (Fay and Yepes 2003) or simple benchmarking with relevant comparator cities/countries (Estache and Fay 2009). The most advanced approach, according to Estache and Fay (2009), includes sector-specific micro-studies combining econometric and engineering models. A key question that emerges from some of the economic work on infrastructure services concerns whether efficiency can only be promoted through either private or public profits.

Questions of which areas to prioritise for infrastructure development are equally complex and usually not considered comprehensively as part of the policy-making process. For example, economic geography (Puga 2002, Baldwin, Forslid et al. 2011) has shown that the common desire of connecting underdeveloped regions with more advanced regions can exacerbate rather than mitigate regional disparities as a result of 'bloodletting' of poorer regions (Estache and Fay 2009, Overman 2012). At the same time, connectivity improvements within metropolitan regions tend to improve geographic imbalances (Henderson and Kuncoro 1996, Henderson 2002). In summary, intra-regional rather than inter-regional infrastructure avoids potentially negative effects on local economic development. Prioritising rural over urban infrastructure investments – and the opposite, focusing infrastructure developments in specific regions over others – are in the end political decisions that techno-policy work can only inform (Estache and Fay 2009).

In terms of the economic performance of cities, Collier and Venables (2016) emphasise the fundamental trade-off between the benefit of greater connectivity in cities and higher costs related to congestion, land and property. They further argue that this relationship is centrally determined by urban infrastructure that can enable efficient land use – a city's 'ultimate scarce resource' (p. 395). In many instances of formal and informal urban development, efficient land use remains a distant goal. At the same time, the advantages of efficient land use in terms of a greater utilisation, efficiency and scale economies for infrastructure provision are increasingly recognised. For example, recent policy-related work on urban infrastructure re-emphasises the cost differentials between infrastructure delivery in lower- vs higher-density urban areas (Litman 2011, GCEC 2014). Collier and Venables (2016) refer to infrastructure costs being three times higher for lower-density development compared to high densities (for Africa, they estimate that this translates to a difference of US$10 billion per annum). Overall, infrastructure services offer a range of multiplier benefits not only to the regional economy of a city but to national economies as well (Revi and Rosenzweig 2013).

Ultimately, however, identifying appropriate levels, sequencing and type of infrastructure provision has to incorporate a financing perspective (Estache and Fay 2009). Finance is a subset of economics that deals with the management of revenue, expenditure and assets related to urban infrastructure. Finance, as a field, is less concerned with questions of what should be funded and where, and more with a question of how to structure flows of money to support delivery.

Infrastructure investments also require upfront finance that is usually only recovered over a long period via tax revenues or user fees. Tax revenues tend to be converted into 'grant' finance, used for infrastructure that is non-divisible and difficult to charge for its use. This includes infrastructure like parks. User fees tend to cover infrastructure services that can be charged on an individual basis, for example water and electricity. In reality, most infrastructures are covered by a combination of taxes and user fees, with user fees aiming to cover the operations and taxes for larger bulk investments. Lee and Floris (2003) note that few utilities (agents tasked with the delivery of trading services) have historically been able to cover costs for operations and maintenance and were mostly entirely reliant on government for capital investments. At the same time, the World Bank (2014) suggests that current tax revenues in Nigeria, Ethiopia and Congo fall short of infrastructure investment needs by a factor of 12, 20 and 26 respectively, confirming the limited scope for the expansion of infrastructure services within the current financial models.

In order to address the financial sustainability of infrastructure provision and utilities, there have been waves of privatisation (Estache and Fay 2009). Privatisation aimed to separate utilities from the state, and ensure that costs were recovered and (where possible) surpluses could be generated. Privatisation has since been relaxed as the de facto intentional development policy and replaced by a drive for corporatisation (Magdahl 2012). Corporatisation continues to ring-fence utilities, separating them from the day-to-day management of the state. However, ownership for the utility remains vested with the state (McDonald 2016).

Within a context of growing fiscal austerity, local governments are increasingly encouraged to borrow to meet their urban infrastructure demands. Creating 'bankable' projects and creditworthy authorities forms part of an increasingly strong narrative within development policy.[1] The main reasons for governments and utilities in developing countries to include debt in their financial management plans are: to accelerate local growth through investment; to make spending more equitable, spreading the payment between current and future users; to support the proper pricing of urban services; and to build the long-term sustainability and autonomy of the institution (UN-Habitat 2009, Paulais 2012, Bird and Bahl 2013, Lincoln Institute and World Bank 2016). When a government takes on a debt, it creates a liability that it must settle over time. The taking on of a debt, also called borrowing, can occur in various ways. The two most common ways of municipal borrowing are through a loan (from a lender) and through issuing bonds (to buyers).

Local governments can take loans from banks. Bank finance includes borrowing from commercial private-sector banks, multilateral development banks (such as the AfDB or the World Bank) and national central banks. In general, banks have short-term liabilities and thus prefer not to make long-term loans (a challenge intensified by the Basel III regulations established in the wake of the 2008 financial crisis) (Arezki and Sy 2016).

Bonds are the most commonly used capital market instrument exercised by governments. Together with loans, bonds are considered 'debt finance'. Like loans, bonds are a finance tool that is available to various levels of government, depending on the country and legislation. Unlike loans, whereby the receiving party often agrees with a select group of financiers on the terms and conditions of the obligation, bonds are generally issued for the purpose of attracting a larger group of investors (Gorelick 2018). Theoretically, the risk and returns on municipal bonds are lower than on other forms of finance. Since the time frames for repayment are long, bonds attract more conservative and long-term investors. The two most common types of bonds are general obligation bonds and revenue bonds. While bonds are a common form of debt financing for local government globally, this has not been the case in the African context. A number of local governments in African countries do regularly raise bonds (for example, in South Africa), but efforts to develop city bonds in other places have stalled (Gorelick 2018).

Social and political readings of urban infrastructure

Social and political readings gained popularity as a response to the limitations of technical readings of infrastructure. The 'Infrastructure Turn' refers to the growing interest that scholars in the social science and humanities have taken in the study of infrastructure (Amin 2014). The seminal work of Star

[1] See the World Bank's City Creditworthiness programme: http://www.worldbank.org/en/topic/urbandevelopment/brief/city-creditworthiness-initiative. Also see the PwC South Africa proposition for local government funding and finance: https://www.pwc.co.za/en/industries/public-sector/material-funding.html

(1999) on the 'ethnography of infrastructure' is one of the most cited texts. It has inspired critical scholars across a range of disciplines (for example, anthropology, planning, geography and political science) to reflect on infrastructure in creative and provocative ways. These authors argue that technical readings of infrastructure create a 'black box' that needs to be opened, interrogated and exposed (Coutard and Guy 2007, Law 2009).

Scholars contributing to the Infrastructure Turn share a deep concern with the instrumentalist, apolitical and ostensibly objective reading of infrastructure common within the technical and policy debates (Ferguson 2012). These authors argue that infrastructure is at the same time political, constructed and contingent. In this sense, infrastructure's development is shaped by embedded, hidden, seemingly mundane and complex power dynamics (Coutard and Guy 2007, Law 2009). The argument is not that infrastructure is both technical and political, but that 'the technical' itself is political.

Urban scholars have joined the Infrastructure Turn. These scholars draw attention to the social and political nature of urban infrastructure and services. While this is obviously simplistic, we identify two dominant scholarly camps within the urban Infrastructure Turn: we term these the 'structural' and the 'relational' urban infrastructure camps. We describe these briefly below. Rather than seeking to provide a comprehensive overview, the intention in this section is to offer an introduction to the debates.

Structural accounts of urban infrastructure

Structural accounts of urban infrastructure explore the ways in which modes of capitalist accumulation can be exposed, and our understanding of their contemporary significance refined, through studies of infrastructure (Ferguson 2012). These authors share a deep concern that the evolving modes of infrastructure provision are producing inequality, fragmentation and deep injustices in cities. Of particular concern are the ways in which urban infrastructure has been privatised and financialised, resulting in enclaves of access and connectivity. Structural scholars see the privatisation and financialisation of urban infrastructure as a response to the failures in capitalist systems – or what might be called an ongoing process of 'creative destruction' brought on by the perpetual failures of orthodox economics (Peck, Theodore et al. 2009).

The most seminal and influential macro/structural accounts are the works of Graham and Marvin. Their two most notable works, Telecommunications and the City: Electronic spaces, Urban Places (1996) and Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition (2001), have inspired a landslide of studies over the past 30 years. In Telecommunications and the City, Graham and Marvin (1996) argue that urban telecommunication infrastructure reproduces and restructures social and economic relations in the city. Building on this in their later thesis in Splintering Urbanism, Graham and Marvin (2001) show how the privatisation of infrastructure creates enclaves of access in landscapes of deprivation, a compartmentalisation and fragmentation of provision and, by extension, cities (Graham 2000).

Building on earlier neoliberal critique (Postone 2007, Peck, Theodore et al. 2009, Brenner, Madden et al. 2011, Ward 2017), there is growing work on the financialisation of infrastructure (van der Zwan 2014). Aalbers (2015) defines financialisation as 'the increasing dominance of financial actors, markets, practices, measurements and narratives, at various scales, resulting in a structural transformation of economies, firms (including financial institutions), states and households' (p. 3). Urban infrastructure, authors argue, can be seen as increasingly financialised both in terms of the rapid privatisation of public infrastructure services and the increasingly complex financial instruments used to propel them (Torrance 2008). In many ways, thinking on the financialisation of urban infrastructure builds on Harvey's 'capital switching hypothesis'. Here he argues that the surplus capital acquired through the 'primary circuit of capital' (i.e. production) is moved to the 'secondary circuit of capital' (i.e. fixed assets and the built environment) (Christophers 2011). Infrastructure becomes an 'asset class' (Hebb and Sharma 2013).

Structural accounts of urban infrastructure have serious appeal. They capture global trends and situate local experiences within broader global processes. They point the finger at the prevailing logic of neoliberal and financialised models of infrastructure provision, the distinctive and calculable operations of risk and return and the destructive consequence of these models. However, structural accounts of urban infrastructure are critiqued for paying insufficient attention to complexity, providing 'crisis' and 'techno-pessimist' accounts and – in their unwavering critique of capitalism – failing to provide space for propositionality and alternatives.

Relational approaches to urban infrastructure

Relational approaches to the study of urban infrastructure are explicitly post-structural (Gandy 2005, Monstadt 2009, Guy and Karvonen 2012). Post-structural critiques reject universalising and reductionist narratives such as capitalism/neoliberalism, as well as false binaries, for example between the technical/social or human/environment (McFarlane 2011, Anand 2012, Ferguson 2012). They tend to use infrastructure to reflect on social and political topics. For example, McFarlane and Rutherford (2008) show how urban water infrastructure sheds light on governance, and the 'civilized subject' in the post-colonial context. And von Schnitzler (2016) uses water meters – and resistance to them – to unpack the 'social life' of technopolitical infrastructures in South Africa.

Relational approaches stress the importance of seeing urban infrastructure through its relationships. Theorising on the 'poetics of infrastructure', Larkin (2013) reflects on the 'peculiar ontology' of infrastructure as both 'things' and relationships between things. Since relationships are constantly being formed, infrastructure can be seen as 'constantly coming into being', and not as a fixed object. These relationships are understood to be complex. By describing and analysing the complexity of relationships, relational approaches embrace messiness. This work does not seek to impose onto infrastructure a dominant/meta structuring order.

Owing to its diffuse and Foucauldian reading of power, relational accounts of urban infrastructure identify power/politics as multidimensional and multiscale (Young and Keil 2010, De Boeck 2011, Anand 2012, Von Schnitzler 2013, Collier, Mizes et al. 2016). Instead of seeking to identify a single 'political project' inscripted into the design of infrastructure, authors work to identify the many political projects and practices that are built into, shape and are shaped by infrastructure (Young and Keil 2010, De Boeck 2011, Anand 2012, Von Schnitzler 2013, Collier, Mizes et al. 2016). Reflecting this commitment to diffuse power, Amin and Thrift (2017) argue that infrastructure drives a 'logic of governance' in cities.

Importantly, the 'critique' that relational scholars levy on technical readings of infrastructure is not focused on exposing the contradictions of capitalism (as the structural account does). In contrast, relational work on urban infrastructure seeks to 'trace effects', exposing the constructed nature of infrastructure and the possibilities for alternative constructions and pathways (Coutard and Guy 2007, Mol 2010).

The relational perspective on urban infrastructure has gained traction within the trend of southern urbanism. Aiming to see southern cities 'on their own terms', there has been a resistance to pre-scripted narratives on urban infrastructure. They seek to describe the real and grounded processes that take place in developing cities. Simultaneously they seek to 'make sense' of the implications of these ways of being and knowing. This work valorises hybridity, informality and other processes that fail to conform to the networked city ideal.

Relational accounts run many risks; infinite particularism and rudderless resistance to normativity are commonly critiqued (Pieterse 2011). Regardless, relinquishing the longstanding structural focus on the fully networked systems undeniably offers opportunities to reframe and reform our understanding of what is possible and desirable from the vantage point of particular cities and contextualised urban experiences.

Conclusion

The need for interdisciplinary work on cities is neither a new nor novel call in the contemporary context and debates. It is widely agreed that the bounded disciplinary registers are insufficient for addressing the complexity of contemporary urban challenges. Using a provocative phrase that leaves much up to the imagination, Amin and Thrift (2017) call for a 'new science of cities', which is multi-scalar, interdisciplinary and multi-register.

There are undeniably many ways to understand and 'make sense of' urban infrastructure. Equally, there are many ways to deploy studies of urban infrastructure to reflect on conceptual questions related to, among other things, cities, development, politics and society. In the earlier sections, we have focused on four important infrastructure ideals and two broad framings that we believe provide valuable insights for shaping this study.

Importantly, infrastructure ideals have shaped the infrastructure arrangements and investment strategies in countries. In many developing countries, these have been shaped by ideals that are propelled within global policy discourse. Equally relevant, the academic study of infrastructure was, until recently, dominated by the technical disciplines. In more recent years there has been more interest from the social disciplines. This goes beyond understanding basic things like the social impacts of infrastructure. It includes the use of infrastructure to analyse social and political concepts and their manifestation in particular places. There is significant conflict between the ideals as well as between the technical and social readings of urban infrastructure. They have underlying differences around epistemological approaches, which translates into different priorities in terms of both knowledge and intervention.

The infrastructure ideals and the two framings that we presented here could sit in productive tension with one another. However, the fundamentally different methodological and analytical tools, ideological positions, aims and objectives and logics of prioritisation make the prospect of a Habermasian utopia of transdisciplinary understanding a distant prospect. In this sense, endeavours to embrace these productive tensions and travel 'a third path' that weaves them together faces difficult questions, trade-offs and compromises.

In an effort to cut through what could become a black hole of intellectual debate, we would like to propose the following:

Technical accounts offer tools that are indispensable to the project of reconfiguration. Without commandeering the technical register, it is impossible to embrace the full breadth of ambivalence and redesign infrastructure in alignment with alternative visions and goals. In order to understand the full scope of possibility and to consider propositions for reconfiguration, it is imperative to commandeer the mechanics and operations of infrastructure logics. It would be a grave mistake to take the easy route wherein all technical intervention is 'decried as tools of domination and surveillance' (von Schnitzler 2013, p. 668) and where all social analysis points away from the infrastructure in question.

Social and political accounts of urban infrastructure draw our attention to the powerful nature of infrastructure; powerful both in the way it shapes places and in the way in which power is inscripted into its design. More importantly, social and political accounts widen the scope for considering alternative pathways. They allow us to read infrastructure as 'ambivalent', described as '[a] process of development suspended between different possibilities.' However, we must recognise that its reconfigurability is shaped by the unique fixities and fluidities that particular infrastructures have. Contemporary arrangements reflect a contingent history of decisions; contemporary options for alternatives are thus neither path-dependent nor infinite.

Where the two approaches/camps come together is in the increasing focus on place-based solutions. Even the very technical work is increasingly attentive to the inability to generalise methodological approach and response. Context and place is increasingly understood to be central to this – as shown earlier, this is the common ground that connects engineering and humanities.

Critically, trans- and interdisciplinary approaches to infrastructure will need to find ways to address the cutting-edge issues within the current context, in particular those with relevance to African and developing cities. There are a range of important issues a propositional lens must contend with. These include issues such as digitisation, which allows for leapfrogging of some of the older infrastructure models, climate change, which equally challenges now-dated models, the end of the commodity boom, which will require new modes of resource utilisation, and the emergence of new lenders, which are shaping the global and African agenda (such as those from Asia).

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