Article

Politics and Space

EPC: Politics and Space
0(0) 1–19

DOI: 10.1177/23996544211037063
journals.sagepub.com/home/epc


Infrastructure governance in the post-networked city: State-led, high-tech sanitation in Addis Ababa's condominium housing

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Abstract

Ethiopia's mass-scale subsidized housing delivery programme has driven the rapid expansion of middle-income, mid-rise settlements on the outskirts of Addis Ababa, requiring the provision of infrastructure to newly developed areas. In the case of the Kotari housing project, established sanitation systems were deemed inappropriate for the site, resulting in the deployment of novel technology, a Membrane Bioreactor (MBR). Such decentralised technologies contribute to the heterogenous infrastructure configurations which characterise Addis Ababa's sanitation landscape, reflected not only in material configurations but also in how they are governed. In this paper, we use the concept of 'infrastructure interfaces' as an analytical device to identify the key material connection points in the system. Working across scales, we scrutinise the governance arrangements at these critical junctures: the household, the block, the condominium, and the city. Our analysis challenges established understandings of infrastructural heterogeneity driven by the private sector, either through financialized elite infrastructures or informal survivalist practices. In Kotari, the state is the driver and the target is the lower middle class. Centring the state in these infrastructure configurations provides nuance to our understanding of how heterogeneity emerges. Our methodological approach accounts for governance at various scales, providing fresh insights into the relationality of infrastructure, particularly the human/technology interface and infrastructural failures. The case shows the importance of transcending binary readings of

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infrastructure configurations, such as on/off grid, state/private and formal/informal. Future work on the post-network city must go beyond simply denigrating or valorising alternative modes of service delivery.

Keywords
Ethiopia, decentralisation, heterogeneity, hybridity, housing, infrastructure interfaces, post-networked city, sub-Saharan Africa, urbanisation, wastewater

Introduction

Ethiopia has become a posterchild of rapid state-led development in Africa (Goodfellow, 2017a). Over the last fifteen years, the government has positioned itself to attract global investment in infrastructure (Mosley and Watson, 2016). Addis Ababa, Ethiopia's capital city, is a site of significant urban expansion with major projects driven by the state, through partnerships with international investors and lenders (Ejigu, 2014). Alongside railways and industrial parks, there has also been investment in housing and the supporting urban services. Like other African countries, Ethiopia's national housing programme is being used to enact the principles of developmentalism (Croese, 2017; Goodfellow, 2017b; Parnell and Robinson, 2012). Addis Ababa's large-scale housing projects are supported by a subsidized mortgage system. The first wave of condominium housing projects was on infill sites. However, later projects were located on the edge of the city. The Kotari settlement in Nefas Silk-Lafto sub-city, the site of our research, is one of these peripheral projects.

In this paper we explore the intersections between the highly political and very visible delivery of state-driven housing projects and the more mundane question of how sanitation is provided to these settlements. Sanitation in Addis Ababa reflects what infrastructure scholars refer to as 'heterogenous infrastructure configurations' (Jaglin, 2014). Rather than a single, universal, and centralized network, as might be expected in industrialised cities, there are a plethora of delivery systems for this basic and essential urban service. Across this heterogeneity, each configuration has different material and governance arrangements. In Addis Ababa, sanitation is variously provided through a networked water-based system, a vacuum truck and septic tank system, and high- and low-tech decentralised technologies (Meinzinger et al., 2009; Z&A and Tropics, 2014). The networked system only serves around ten per cent of the urban population. Most households and businesses have septic tanks, serviced by vacuum trucks which dump the wastewater at 'transfer stations', eventually reaching one of the city's treatment plants. These have ample bulk capacity to treat networked flows, having recently been upgraded at great cost. However, shifting from septic tanks to other solutions has proven difficult as most users prefer this well-established system. In addition, decentralised systems have become important in the context of Addis' rapidly expanding urban fabric, springing up in the newly developed peripheral settlements, which cannot be serviced by established delivery models. Some are low-tech – often space intensive and entailing dis-amenities such as bad odours and even localized flooding. Others are high-tech, compact and expensive.

We focus on a particular sanitation delivery configuration used in one peripheral settlement, the Kotari condominium project. Here and in a few other sites, Membrane Bioreactor (MBR) technology is used to provide on-site treatment. At the time of collecting this data, the City has purchases twelve MBR plants from various countries. Kotari's came from a

Portuguese supplier whereas the plant in the neighbouring Oromia condominium complex came from Greece. In the new Koye Feche condominium project, there are plans to test up to eight different high-tech options. Heavily contested initially, decentralised and high-tech sanitation systems are growing in importance in Addis Ababa, as the City Administration works to meet demand. These solutions have been framed as 'temporary interventions' until such time that the networked system can catch up. However, it is unlikely these settlements will be served by the central grid in the foreseeable future.

Empirically, Addis Ababa's sanitation is understudied. While technical studies are undertaken by engineers, social and political analysis of sanitation has been minimal, especially in relationship to housing delivery. The Kotari case also offers theoretical purchase as it confronts established understandings of infrastructural heterogeneity. In particular, it challenges the idea that heterogeneity and material splintering is driven by the elite and informal private sectors, responding to gaps left by the state. The MBR in Kotari represents a decentralised and high-tech arrangement driven by the state and targeted at the lower middle class.

The creative use of a methodology drawn from multiple disciplines provides much needed specificity, allowing us to contribute to infrastructure debates. Mapping material infrastructure interfaces and tracing their governance, provides fresh insights on common themes, notably the ways in which infrastructure works or fails and what it means to be both on and off grid, at the same time. We conclude that future work on the post-network city needs to go beyond simply rejecting the networked infrastructure ideal or celebrating alternative configurations. Responding to the plea for grounded research from Southern urbanists, we offer nuance and granularity that challenges normativity as various and complex technologies increasingly shape African infrastructure-scapes. This advances the debates on how, and for whom, decentralized technologies operate in practice, and challenges uncritical celebrations of post-networkedness.

Infrastructure: Material interfaces and governance configurations

The last two decades have seen a growing body of work within urban studies concerned with infrastructure. Challenging technicist framings, driven by engineering, finance, economics, and planning (Coutard and Rutherford, 2016), a focus solely on hard utilities and material networks (Estache and Fay, 2009) has given way to perspectives on infrastructure as contributing towards how cities and citizens are made (Anand, 2017; Anand et al., 2018; Jensen and Morita, 2017; Lemanski, 2019; Marvin and Medd, 2010; Power and Kirshner, 2019). In this section, we outline the substance of this infrastructural turn within urban studies, with particular attention the emergence of the concept of heterogeneous configurations.

Infrastructure as a lens of social and political theorization

The 'infrastructure turn' (Amin, 2014) within urban studies was multidisciplinary. Science and technology studies deployed methodological tools from history, anthropology, and geography to understand the 'social lives' and 'situated histories' of technical devices deployed in urban environments (von Schnitzler, 2016). A social-technical understanding of urban infrastructure emerged on how technical systems underpinning urban life are coproduced by human processes. Similarly, urban political ecology focused on the intersections between natural systems, politics, and infrastructure, blurring the "artificial distinctions between nature and the city" (Coutard and Rutherford, 2016: 6). This extended to

and politicized socio-technical work on infrastructure (Lawhon et al., 2014; Silver, 2017; Williams et al., 2014).

Urban infrastructure and service delivery systems were used as lenses for social and political inquiry. In the context of African cities, scholars have deconstructed and problematized both oppression and resistance: water meters were used to critique Johannesburg's contours of democracy (von Schnitzler, 2016); water pumps to confront reinstallations of empire and resistance in Nairobi's slums (Kimari, 2019); 'poo' to understand power and protest in Cape Town (McFarlane and Silver, 2017); and trash to understand labour politics and social action in Dakar (Fredericks, 2018). Such studies have been alert to the people, practices, power dynamics, discourses, and imaginaries embedded in material infrastructure systems (Amin and Thrift, 2017; Furlong, 2011; Picon, 2018). New vocabularies emerged from these contributions to social and political theorisation. In the context of Southern urbanism, Silver (2014) used the concept of 'material improvising' to show how people adapt networked systems; Simone (2004) discussed 'people as infrastructure' to foreground the role of the human body in/as infrastructure; Pieterse (2013) wrote on 'radical incrementalism' to imagine how small infrastructural practices can contribute to emancipatory projects; and De Boeck (2013) and Amin (2014) explored the 'absence-presence' of infrastructural gap-filling.

The commitment of such studies to rethinking the very nature of urban infrastructure and to resisting grand narratives and normative assumptions, influenced some of the most seminal contributions to the infrastructure turn. Through deep empirical inquiry across a wide range of geographies, and alongside understandings of the diverse and distributed nature of power, this work served to enliven the splintering urbanism debate to which we turn.

From splintering urbanism to the post-networked city

An anchor contribution to the 'infrastructure turn' is *Splintering Urbanism* (Graham and Marvin, 2001), which describes the material, social, spatial, and political processes that underpin the fragmentation and failures of urban infrastructure systems. Privatization and financialization of service provision manifests spatially in elite enclaves of high-quality provision. Gated communities, tech-hubs, and mall complexes consolidate infrastructure, packaging projects for investors and the lifestyles of global and local elites, resulting in the hollowing out of state-provided networked systems and exacerbating spatial and social inequality across cities and regions (Tapp and Kay, 2019). At their core, studies of splintering urban infrastructure systems exposed how capitalist modes of urbanization, the financialization of infrastructure and real estate, and the emergence of entrepreneurial urban governance, splinter urban systems. They create enclaves of access, disregard networks, and lead to makeshift alternatives. Scholarship on infrastructural failures and disruptions simultaneously argued that urban infrastructure is invisible when it works but becomes highly visible when it fails (Graham, 2010). Such infrastructural breakdowns are endemic to capitalist modes of urbanization but are experienced as shocks in the urban system.

Scholars operating from Southern ontologies have critiqued 'splintering urbanism', the implicit 'networked infrastructure ideal', and its commitment to structural readings of modes of capitalist accumulation (Pilo, 2021). While remaining critical of engineering-led understandings of infrastructure, such scholars point to the intrinsic commitment of the splintering urbanism thesis to engineered and networked solutions as essential to building the just city (Jaglin, 2016), and to generalizations over infrastructural failures. In Southern contexts disconnections, patchworking, and partiality are the norm, rather than the exception. Moreover, the assumption that cities *should* be part of a homogenous network, does

not reflect the empirical realities of many Southern cities, particularly in sub-Saharan Africa (Coutard and Rutherford, 2016; Jaglin, 2016). Here, the state has never fully provided networked public services and infrastructural failures are usual. Consequently, consideration is given to the incremental and multi-dimensional ways in which infrastructure is configured and reconfigured in cities.

The concept of the 'post-networked city' emerged as a critical response to the networked infrastructure ideal, valorising alternative infrastructure arrangements (Coutard and Rutherford, 2016). For some cities, pursuing a fully networked infrastructural system meant failing to recognize the burden of such aspirations on natural and fiscal systems, and overlooking the heterogeneity and diversity in how services are actually accessed (Beall et al., 2019; Bhan, 2019). 'Heterogenous' or 'hybrid' infrastructure configurations are concepts used to refer to the diverse ways that people access services within and beyond conventional city networks (Cirolia, 2020; Jaglin, 2016; Lawhon et al., 2018). The term 'configuration' (often used interchangeably with networks, assemblages, arrangements, *dispositifs*) helps to draw attention to the relational, distributed, and complex dynamics involved in shaping infrastructure and service delivery, whether material, social or regulatory (Larkin, 2013; Schramm and Ibrahim, 2019; Silver, 2014).

The concept of heterogenous configurations accommodates diverse alternative service delivery – on and off-grid, publicly, privately, cooperatively and 'informally' provided, small and large scale – and challenges the binary between networked and non-networked infrastructure systems implied by modern infrastructure ideals. This literature often assumes that decentralised infrastructure systems are more labour intensive and less heavily engineered. Our study of high-tech decentralised infrastructure solutions muddies this picture and deters new conceptual binaries. Advanced technologies such as energy mini-grids and the sanitation MBR plants discussed here, reflect an evolving new engineering imaginary where infrastructure tech-fixes are not confined to centralized networks.

Governing heterogenous infrastructures

Key to understanding heterogeneity is to identify how particular infrastructure configurations are governed (Levenda, 2019). This includes investigating the actors and power dynamics involved in financing, developing, maintaining, and even diverting configured technologies and flows. Multiple actors are involved in service delivery, forming part of the governance apparatus of the built environment in Southern cities (Lindell, 2008; Smit, 2018). Small-scale private operators, local entrepreneurs, informal providers and community organisations, are all involved in the provision, operation or maintenance of urban infrastructure (Amin and Thrift, 2017; McFarlane and Vasudevan, 2014; Silver, 2014). While common in the discourse, in practice, 'formal' or 'informal' dichotomy does not apply. Different components fall within and beyond various regulatory frameworks. Such highly localized and heterogeneous systems require fine-grained institutional mapping (Simone and Pieterse, 2017). The resulting thick, if fragile, fabric of infrastructural access, is what Jaglin (2014) refers to as 'hybrid' service delivery configurations, made up of different material arrangements and delivered by a range of actors.

Most literature on the post-networked city and heterogeneity focusses on non-state and informal actors, filling gaps in state provision. However, there are cases, such as the one we present, where the state itself fills gaps in its own fragmented delivery systems, with multilateral donors and lenders often playing central roles in developing new configurations. Understanding the granularity of relationships between all these actors is core to understanding the governance of heterogeneous arrangements. Reflecting on the relationship

between networked and post-networked services in Southern cities, Bhan (2019) underscores the importance of studying city infrastructure on the ground and on its own terms, before identifying how and by whom intervention is needed:

> "[We] *must begin from existing practices of service delivery on their own terms, recognize the contexts that they come from, understand why they have emerged, and then reassess whether the network is the most feasible (and not just the most theoretically desirable) mode through which to reach the outcomes we want*" (Bhan, 2019: 649).

The case of the MBR technology in Kotari illustrates a multiplicity of material and governance dynamics in Addis Ababa's sanitation system and our study was undertaken in this spirit. Infrastructure interfaces in the city served as vehicles for social and political theorization at the same time as empirically exploring, heterogenous service delivery in city development processes. This shows us to three important things. First, the role of the state in heterogeneous configurations and in driving hi-tech, decentralised solutions is key. Second, the need to go beyond conceptual valorisation of heterogeneity in infrastructure is foregrounded. Third, and elaborated in the following section, the case demonstrates the value of using creative and multidisciplinary methods (Beall et al., 2019) for interrogating infrastructure governance and rationality and for enhancing conceptual and empirical debates in relation to Southern urbanism.

Methodology: Multi-scalar infrastructure interfaces

The concept of 'infrastructure interfaces' provides a methodological scaffolding to unpack the complexity of service delivery configurations in this case (Beall et al., 2019). Infrastructure interfaces are the physical connection points where different components and agents of the systems meet. These are the points where things change – not just the materials and flows but often also the jurisdictions. Our empirical research, using a case study method (Agranoff and Radin, 1991; Yin, 2013), focusses on sanitation provision in the Kotari condominium, in Addis Ababa, Ethiopia's dominant urban hub. Picked as a fast-growing city of particular relevance for the study of post-networked urban services, the Kotari site and its specific infrastructure interfaces were identified at early stages of data collection and analysis.

Examining infrastructure interfaces offers a tool to explore technologies, capacities, design lives and scales, as well as the role of disciplinary expertise and professional boundaries at these critical junctures (Rode et al., 2020). They are places where different actors collide and collude and where everyday politics play out often in mundane ways. They provide a useful analytical entry point to explore components of multi-scalar infrastructure systems, and how different actors responsible for the design, operation, connection, adaptation and coordination of various components and uses, engage (or disengage) at these points. The inherent complexity of infrastructure interfaces makes them 'hotspots of urban governance' (Beall et al., 2019), typically involving considerable levels of governance hybridity.

We traced the sanitation flow as it moved through space. By conducting architectural, engineering and spatial analysis of the Kotari site, we identified specific material points, mapping the flow of wastewater from the household to the MBR plant, revealing key physical intersections where infrastructural components at different scales meet. The mapping allowed for a careful consideration of relational acts as well as the appearance of sites, through tracing associations between places, people and processes, separated by distance.

Hence the mapping aligned with anthropological and relational methods that follow the social life of infrastructure but added exploratory and critical visual practice to illuminate socio-spatial relationships in their temporal, scalar, as well as socio-cultural dimensions.

The multi-scalar scaffold across this configuration, included the household, the housing block, the condominium project, and the city as a whole. Each interface required a slightly different approach to data collection. The combination included: spatial mapping, interviews with households, officials and consultants; observational visits to Kotari (including spending time with selected families in their homes); photo documentation and sketches of the material interfaces; review of plans and policy documents relevant to the case; and a stakeholder workshop held in Addis on 5 December 2018, where we received critical feedback on the analytical approach and initial research findings. All data collection took place in the final months of 2018 and early 2019.

Housing and sanitation nexus in Addis Ababa

In this section we explore the material and governance context within which sanitation heterogeneity emerged in Addis Ababa and Kotari. This requires grasping the complex nature of urban governance in the capital city and the proactive role of the state in shaping infrastructure through subsidized mass housing. Ethiopia is an ethno-federal country with multi-level government, including national, regional (state) and local government. Surrounded by the Oromia Regional State, Addis Ababa is constitutionally 'chartered' as an autonomous regional government. The City thus has significant levels of power over infrastructure and service delivery, including water and sanitation. There are 10 'sub-cities', each with its own administration and, in line with Ethiopia's decentralisation policy, the City is further divided into municipal districts. The lowest level administrative units are known as *woredas,* with solid waste collection and maintenance of public spaces among their responsibilities.

Since 2005, the rapid delivery of state-subsidized mortgage housing has been a priority in Addis Ababa (UN Habitat, 2010). The City Government is responsible for implementing the national Integrated Housing Delivery Programme within the city area (Ozlu et al., 2015). Delivery statistics vary but a commonly cited number by City administrators was 178,000 condominium units delivered and another 207,000 planned (Wubneh, 2013). Initially the aim was to build on small infill sites within the built urban fabric, however, this was soon abandoned in favour of projects towards the edge of the city (Yntiso, 2008). The programme has been criticised by academics and policymakers (Ozlu et al., 2015). One concern, shared by many state-driven housing programmes globally, related to the peripheral location of housing projects (Yntiso, 2008).

The Kotari condominium project is located on the south western edge of the city on a site that just 10 years ago was farmland. Built at the intersection of the Addis Ring Road with Transafrica Road, clusters of five storey pastel-coloured, rendered buildings, are encircled by wide roads and large tracks of empty land awaiting development. Within the City's jurisdiction, Kotari sits on the boundary with the Oromia Region, forming part of a multi-site neighbourhood still being developed, including an abutting mid-rise residential project constructed by the regional government of Oromia around the same time (Habtamu International, 2011).

Housing is delivered directly by the City. In contrast, sanitation provision falls under the Addis Ababa Water and Sewerage Authority (AAWSA). Controlled by a Board of Directors, AAWSA is the sole public body mandated to provide sanitation services of any kind. It is responsible for trunk sewage and the public vacuum trucks serving most

of the city. Like many utility agencies in Africa, AAWSA is controlled by City government but operates with partial autonomy to develop and manage water and sanitation in Addis Ababa. AAWSA recognises its highly subsidized model of delivery and limited capital budget means networked delivery is not possible for all parts of the city (Z&A and Tropics, 2014) and decentralised technologies are increasingly used for new housing projects. Some are low-tech, such as the use of stabilization ponds (Abebe and Demoze, 2017) but in other areas, high-tech, on-site solutions such as micro wastewater treatment plants have been adopted.

In 12 condominium sites, decentralised high-tech MBR solutions were chosen to address the urgent sanitation needs of rapidly erected large-scale housing, including Kotari. MBRs are small-scale wastewater treatment plants that rely on microfiltration and sludge activation. The process transforms sewage on site into clean water that can be re-used for other purposes. It is an attractive option for municipal authorities aspiring towards green economy approaches. In the following section, we analyse the infrastructure interfaces of Kotari's unique sanitation infrastructural configuration, inextricably linked with the housing question in Addis Ababa.

Sanitation interfaces: A multi-scalar empirical exploration

In this section, we delineate the historical and spatial junctures in Addis Ababa's recent development and use interdisciplinary methods to show how and why Kotari adopted MBR technology and the heterogeneous configurations that followed. We show how the state was central to its procurement. We also show that people and their everyday labour proved fundamental to shaping how and where infrastructure 'worked' and 'failed'. Kotari was initially designated to be linked to the city's trunk sewage network but the site was too far away and too large to be serviced by network solutions at an acceptable cost. The septic tank connected to a soakaway which was built when the site was first developed could not manage the volume of waste due to erratic water supply and increased flow into the system as the population grew. Blockages, largely from solid waste build up, meant the system would overflow, causing flooding and bad odours. Owner-residents had saved for and paid deposits, so despite mortgages being subsidised by the state they felt entitled to a decent service. Many complained to AAWSA demanding improvement. The City government rethought sanitation services for peripheral condominium sites, and today, both the Addis Ababa and the Oromia condominium developments are serviced by MBR sewage treatment plants.

The two MBR plants are located side by side, at the south-east entrance of the Kotari site next to the highway, adjacent to the now defunct soakaway system. This enabled the existing networks of sewer pipes to be used to connect the Kotari housing to the new treatment plants. The MBR systems are barely visible to the untrained eye and only emit a faint smell, not of effluent but of bio-chemical reactions.

What follows is analysis of the four key infrastructure interfaces identified in Kotari's sanitation configuration (see Figure 1). The first is in the home and materialises at the flush toilet. The second is at the block level, where the focus is the manhole, the point where flows from many households and buildings converge. The third interface is at the condominium level and is the MBR treatment plant. The last is the interface between the condominium project and the City and how this decentralised sanitation system fits into city-wide sanitation solutions. At each interface, we explore empirically, the material and governance dynamics sustaining its operation.

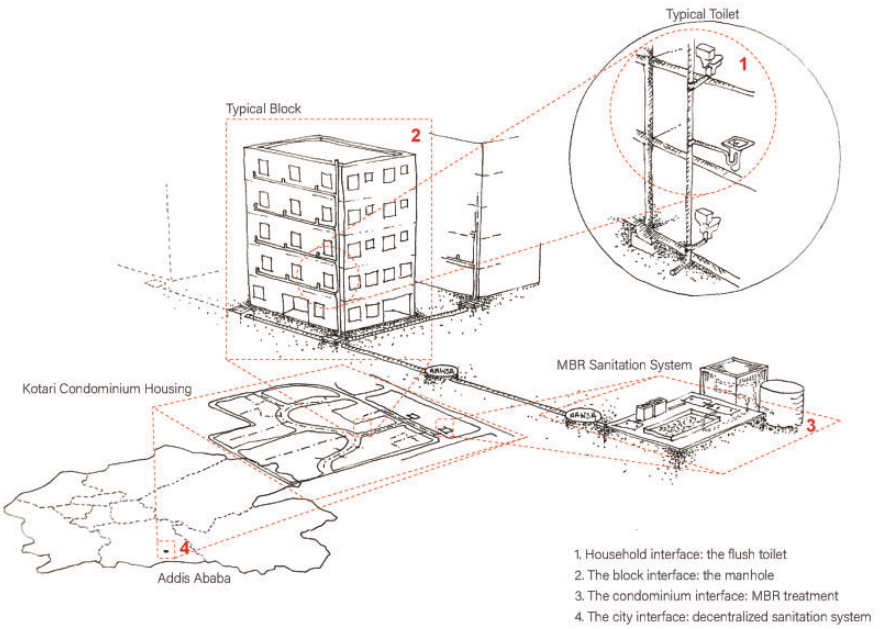

Figure 1. Sanitation infrastructure interfaces at different scales.

Household interface: The flush toilet

Originally intended for owner occupation, residents of Kotari's condominium housing combine original owners, newer owners and tenants. Residents exhibit varying degrees of economic security and social commitment to their dwellings and the condominium. Apartments vary in size and the quality of fittings, but all are equipped with sinks, showers, and at least one standard flush toilet. Serviced by s-traps, soil and water pipes, the toilet represents the primary interface between the resident users and the sanitation system. Whether owners or tenants, residents have to legalise access to their toilet connection by registering at the local branch office of AAWSA, in Kotari's case, in the sub-city of Nefas Silk-Lafto. The process is generally straightforward, involving no other intermediaries.

Intermittent water supply to the condominiums causes flush toilets to back up, representing the main challenge at the household scale. Limited and uneven water supply prevails across the entire city and people keep large water containers in their kitchens and bathrooms for when mains connections run dry. Tap fixtures get left on when the supply is cut off, then gush when the supply resumes, causing flooding. In condominiums, if left unnoticed flooding affects not only the user's home but floors below. Such issues are typically raised with the condominium cooperative who, although not responsible for individual properties, acts as local mediator among affected households.

The use of toilets for general disposal also causes clogging and blockages in the system. Kotari residents flush away all manner of waste products, from menstrual pads and disposable nappies, to kitchen waste. Drains sometimes get clogged by animal bones. Central to many religious and cultural practices, carcasses or part carcasses are bought whole, then skinned and boned at home. In high density condominium housing, the toilet becomes a site for disposal, particularly blocks without communal kitchens for slaughter and butchering.

As such, this infrastructure interface becomes integral to the social and cultural fabric of households, with cultural practices burdening actors along the entire spectrum of service delivery affecting the entire system. An MBR mechanic reported such clogging as the single biggest problem in the treatment process, requiring regular checks of the filtration system.

From the daily filling of jugs and containers, to the disposal of unwanted waste, alongside cultural practices related to food preparation, the toilet is where a range of everyday practices and gendered routines are most acutely visible. Water supply, solid waste management and community facilities also sit at the heart of how the operation of sanitation infrastructure affects the household level. Together they impact on how the toilet, the primary interface in households, articulates with the sanitation system at condominium level and beyond. Formal and legalisation processes (e.g. connection certificates) and community management structures (cooperatives) represent the intersection points where governance, socio-economic status and cultural practices intersect, in the context of infrastructure services delivery.

The block interface: The manhole

From household toilets, wastewater moves by gravity. It flows through pipes, mostly cast iron though sometimes plastic, dropping down a building's façade. Junction boxes, vents and soil stacks are all visible on the outside of the buildings, once household flows are merged, pipes at ground level connect into manholes which direct the waste away from the apartment blocks into a network of larger pipes beneath the ground. Typically, one building complex will have between three and five manholes, moving waste into the neighbourhood sewer network. They are located on public pathways or in the gardens of ground floor flats. Materially only visible by their access covers, these manhole junctions represent the first instance where wastewater becomes a collective responsibility.

The Kotari site has 101 five-storey buildings of studio, one-, two- and three-bedroom apartments (Habtamu International, 2011). For governance purposes they are divided into five 'blocks', each managed by a cooperative run by resident volunteers. These cooperatives raise funds from a levy on residents and through leasing their communal buildings for commercial and community activities, such as making *injera* (Ethiopian flat bread). The experience can vary tremendously from one block to another. For example, the Shallom cooperative serves more affluent residents and is perceived as well run, deriving funds from three communal buildings. Two are rented out to clubs and organisations. A third is specifically designated for butchering lamb. In contrast, a neighbouring cooperative called Heaven only rents out one of its three communal buildings and has no designated space for preparing carcasses. Here households more frequently use their toilets for disposal, causing greater clogging at the block-scale. Collective action differences among blocks in Kotari were difficult to fully discern, although income levels and differences between owners and renters were offered to us as possible explanations.

In Kotari, there are two types of manholes, distinguished by their marking. Unmarked covers are the responsibility of the cooperatives. AAWSA marked covers are technically the responsibility of the Authority, maintenance falling to their sub-city branch office technicians. AAWSA governance structures do not filter below sub-city level to the *woreda* or block level. The cooperatives elect from their members 'technical committees' who are left to fend for themselves in terms of day-to-day and emergency maintenance of manholes. An enormous maintenance gap at the local level exists as a result, with these condominium projects being dislocated from city-wide management and the overall planning and delivery of sanitation infrastructure and services.

The cooperatives' voluntary technical committees deal with complaints emanating from their respective blocks. They are seldom noticed or acknowledged by city-level state structures and yet cooperatives are the key actors at the block interface. They span formal governance through decentralised administrations, notably the *woredas,* and amorphous arrangements with engaged citizens and households within the block. Without them, the institutional thickness that results would not exist. It is the cooperatives that coordinate the women's committees to educate new residents on how to look after their toilets, or to engage recalcitrant households in the blocks. It is the cooperatives that deal with blocked sewers across the condominium. Depending on where the blockage is and the marking of the manholes, they either call on AAWSA or employ informal labourers to clear the sewers. The latter might come from their own local networks, or are drawn from the pool of unemployed people availing themselves for work as part of a local social 'safety net' programme operated at *woreda* level. The Community Participation Offices of the *woredas* have a wide network of 'safety net' actors who access welfare in exchange for work.

The manhole interface elucidates gaps in infrastructure provision due to government institutions being decentralised to different scales. This is compensated for by hybrid processes of manual maintenance, repair and management that are well understood by residents, cooperative committees and low-tier administrators alike, but remain invisible to higher tiers of governance. The manholes, representing material nodes of the decentralised system at the level of the block, receive differential treatment and management. A blurred boundary is transgressed in hyper-local responses to infrastructure management at municipal level and below. What it shows is even high-tech systems need to rely on basic, low-tech practices and material configurations. Lastly, we identify through the lens of infrastructure interfaces, what could be but are not yet, additional configurations in sanitation governance, for example the integration of welfare-to-work scheme in effectively managing (for example through training) sanitation governance.

The condominium interface: MBR treatment plant

A network of shallow, small diameter sewers channels waste from the various blocks into principal sewer lines, which eventually lead through a single large connection to the MBR treatment plants. The main sewer line running along the southern and eastern borders of the Kotari site, connects the sewer at the southeast corner no longer to the septic tank but the two MBR systems. This last access point, hidden behind a lay-by, is distinguishable only by its size, a large concrete slab with no markings. At this critical point Kotari could be disconnected from the MBR plant and connected to a main sewage network if that were to happen. The other critical role performed at this point is to regulate the flows or even switch the operation between one or other of the two MBR plants. This is a key element of the material configuration of the interface, involving different providers, Addis Ababa City and Oromia state. The flows from the two condominium complexes meet at this single access point, before being directed to the treatment plants. Workers can manually switch and regulate the flow of wastewater going to each MBR plant. Having the two ensures service continuity for both housing developments, should one facility fail or need maintenance. Nevertheless, there are issues. A worker from Tsemex, the private Ethiopian contractor tasked with running the MBR plant sourced from the Portuguese, complained they dealt with all the sewage because the Oromia treatment plant was consistently inoperative.

From this infrastructure interface a final piped connection to the MBR sees the treatment process begins. The plant has a treatment capacity of 1,200 m^3 per day, taking raw sewage through discrete processes to convert it to clean water. It is an energy intensive process that

begins by separating out larger solid particles such as grit, a by-product of the system. The most visible and important component is an aeration tank where the sewage, already screened for particles and now resembling murky water, enters a tank and is filled with oxygen. The biological breakdown of the material in open tanks only smells close up but in the event of electricity cuts, aeration stops, with an unpleasant impact on the local environment. The final part of the process relies on a series of micro filters to treat the wastewater until it is clean and can be stored locally for re-use.

The key actors at this material interface of the Kotari sanitation system are private contractors. At the neighbouring Greek site, an AAWSA engineer was present, shadowing the contractor to learn how to maintain the system. These actors confine themselves to this interface, with little interaction with the cooperatives or households upstream, despite one contractor confirming he often had to remove bones that made it through to the primary holding tanks. However, at this interface, there is local engagement with downstream flows. MBR systems are capable of producing up-cycled components, such as grit and clean water that can potentially be re-used. Present capacity is low. Most water from the plants gets discharged into a small creek running alongside the site. Still, some is used by a privately-owned micro-enterprise car wash located adjacent to the Kotari MBR system (see Figure 2 which also spatialises some of the key practices at the other interfaces). Negotiation with the MBR contractors sees water pumped at night from the MBR to storage tanks in the car wash facility. From here it is sold informally to truck and taxi drivers and *tuk tuk* operators wishing to wash their vehicles. Any greater ambition for use of up-cycled water or grit has thus far been thwarted by lack of knowledge by the actors involved, and no formal enabling management structure for such innovation to take place.

As with other interfaces, the most vulnerable element is the weak governance connecting this material infrastructure component to wider city networks and flows. First, power outages can shut the system down. The MBR system assumes consistent flows of water and electricity and neither hold for Kotari or Addis Ababa more generally. Second, anticipating intermittent supply, Kotari residents are parsimonious in their use of water. This means the system constantly runs at about a third of full capacity, making an already expensive

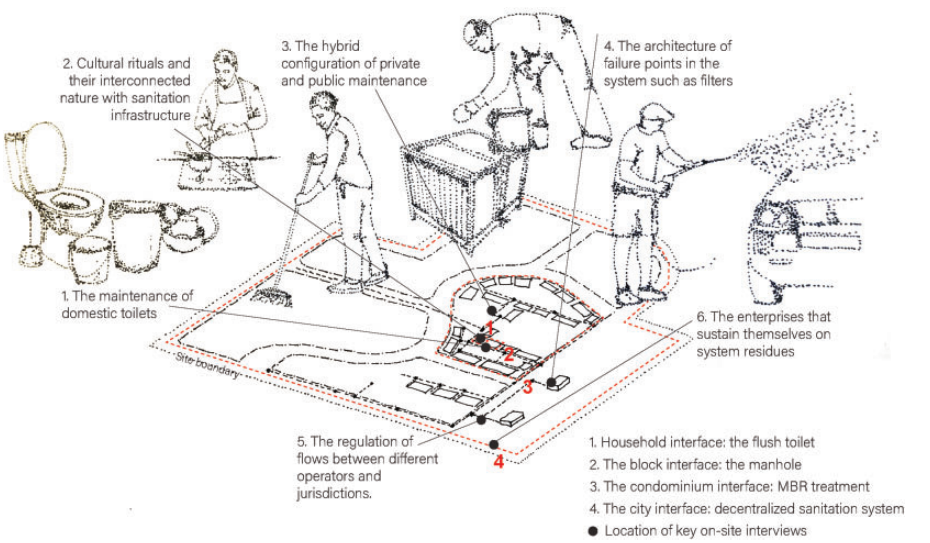

Figure 2. Conditions and practices at Kotari's sanitation infrastructure interfaces.

sanitation solution even more costly (per volume of wastewater treated). Third, blockages are an issue here too, although at the MBR plant interface, they are dealt with by the private contractors. At this interface and scale it becomes particularly apparent just how far the sanitation system is compromised by the dysfunctions of other city-wide infrastructure systems, notably water and electricity supply, rendering vulnerable a decentralised sanitation infrastructure system due to poor or absent connections to other infrastructure services. This in turn is due in large measure to a failure of coordinated infrastructure governance. Discrete governance structures have failed to recognize the MBR as part of a wider post-networked city, involving an array of actors and agents, all central to the functioning of the system.

The city interface: Decentralised sanitation system

In a material sense, Kotari's MBR system does not connect to the centralized sewerage network for the city. It functions separately as a mini grid on the outskirt. Reticulation and distribution networks do not reach the far-flung edges of the metropolitan area, even though there is sufficient bulk capacity at the treatment plants. In fact, one of the main plants – Kaliti, which is also the closest to the Kotari site – is only operating at a third of its designed capacity.

The use of MBRs for condominium housing is not seen as second best but fits neatly with a wider 'modernity' strategy, pursued by national and local government (Terrefe, 2020). Responding to the immediate demands of new housing projects, the sanitation master plan states: '[d]ecentralised wastewater treatment can provide a long-term and cost-effective solution for communities by avoiding large capital costs, reducing operation and maintenance costs and promoting business and job opportunities' (Z&A and Tropics, 2014: 10). Hence, MBR and similar technologies are regarded as optimal responses in a fast-developing city. They are presented as essential to the rapid development agenda, allowing state-driven housing delivery to outpace networked infrastructure investment. They represent potential 'green innovations', reducing ecological costs and burdens such as sewage contamination. The ability to upcycle clean water through the MBR technology constituted an important element of the rationale.

AAWSA continues to scrutinise Kotari's MBR and similar technologies. Like all Addis Ababa City entities, it is going through reform and the Authority's newer staff are less convinced than their predecessors of the efficacy, affordability, and green credentials of high-tech decentralised treatment systems. The newly appointed General Manager, previously a lecturer at one of Ethiopia's technical universities, noted with annoyance that, of all the new technologies for sanitation, 'it is the MBR I dislike most of all'. Rather than being selected and procured based on technical criteria, he believed the decentralised systems had been purchased under duress to secure rapid response. This prevented thoughtful consideration of the long-term appropriateness of the technology for Addis Ababa. A special advisor to AAWSA pointed out that the MBR technology allowed unserved condominium housing to become fully operational swiftly but he was concerned it was expensive, energy intensive, too reliant on imported materials and parts, and requiring high levels of human capability to operate and maintain it.

In a governance sense, the long-term fiscal and coordination challenges of these technologies remain to be seen. Currently, governance of the interface between the MBR plant and the City rests on a couple of private sector contractors managing the MBR plants and an understudy. High-tech decentralised solutions carry enormous potential in the context of a post-networked city but only if they can secure the support of vertically and horizontally

joined up governance structures to guarantee the long-term operation and affordability of the system and its replication.

Conclusions

We explore decentralised sanitation through the case of Kotari condominium in Addis Ababa. Deploying a relational and multi-scalar approach alongside multidisciplinary methods, we follow the sanitation flow from domestic flush toilets to a MBR plant. This tracing unpacks the governance of a high-tech, localized sanitation system via the scrutiny of key material infrastructure interfaces. MBR treatment plants are only one of many ways that residents in Addis Ababa access sanitation. As such, they form part of a heterogeneous system involving a variety of technologies, large and small, networked, and decentralised. Examining the operation and governance at each sanitation interface in Kotari offers valuable insights that inform infrastructure debates within urban studies, with particular reference to Southern urbanism.

First, the case shows that the drive for state-led housing not only changes the urban form of cities, pushing the edge of the city into surrounding regions, it also makes the underlying infrastructure configurations of cities more heterogenous and diverse. Sanitation and housing are rarely put into direct conversation, yet Addis Ababa has seen the rise of new modes of sanitation precisely because of the nature of state-led housing delivery; built on the periphery where networked systems could not keep pace. Our case highlights the complex material and temporal trade-offs in mass housing delivery, often made through highly political processes, and enhances our understanding of the inextricable links between spatial form, urban housing stock, and the governance of service delivery systems.

The state's role in the development of the post-networked city, points to infrastructural heterogeneity in the governance of decentralised technologies. Within the existing literature, decentralised technologies are generally associated with low-tech options in informal settlements, or with privately financed solutions in elite enclaves. The role of the state is understood through its 'absence-presence', anti-poor regulations, or vested interests in the real estate sector. As such, the state is deemed central to the formation of privately provided service systems, both for the poor and elites. Our case articulates the centrality of the state but in relation to decentralised, off-grid and sophisticated technologies as part of public housing provision targeted at the lower middle class. Employed to mitigate gaps in its own planning, the state aimed to ensure the viability of visible housing development delivery and a subsidised mortgage scheme, it also sought to provide material evidence in support of its 'green infrastructure' discourse. Rather than framing decentralised and localized technologies as private sector or informal responses to the failure of a state to achieve a networked infrastructure ideal, the Addis Ababa case reveals how a state can be central to the production of urban splintering while at the same time, potentially becoming part of an emergent material heterogeneity. Our case is interesting because it reflects a sort of partial network, inserted in the gaps left by slow state provision processes by the state itself. As an in-between case, it traverses the on- and off-grid binary embedded in the post-networked city/splintering urbanism debates.

Second, our lens of infrastructure interfaces in the Kotari case vividly illustrates how highly technical systems in contexts such as Addis Ababa, necessarily rely on low-tech and power-laden labour relationships to sustain their functioning. Scholarship within the 'infrastructure turn' has insisted for decades that infrastructure relies on human processes to sustain, mend, and mediate systems. Whether networked or decentralised, infrastructure articulates with social practices and processes, blurring human and technical boundaries.

The use of mapping to trace infrastructure interfaces, and methods that identify specific social, cultural and governance domains intersecting with material and technical ones, illustrate the co-production of heterogenous infrastructural configurations. The operation of the high-tech MBR, relies on the on-going efforts of residents, cooperatives and casual and welfare-to-work labour. Equally, its provenance depended on the willingness of particular politicians and officials to bypass bureaucratic supply chains in its procurement.

Tracing governance connections downstream and upstream of the different infrastructure interfaces of the MBR also contributed to our understanding of infrastructural failure. The localized nature of the MBR means it is more or less visible depending on whether the technology fails or works optimally. Failure is experienced differently when it occurs within different interfaces. When the treatment plant fails, the on-site engineer can flip a switch, without affecting residents. As with the vast majority of sanitation systems, at the household scale it is usually the responsibility of its residents. More unique, perhaps is failure at the block level. It is here that situated, hyper-localized, manual systems have been developed to respond. The most interesting innovations are not to be found in the complex, high-tech interfaces with the MBR plant, but rather in the hybrid and banal engagement with this sophisticated technology through everyday human and ecological processes. As we show, it is in the material interfaces that the specificities of such engagement become most apparent.

Lastly, our findings do not suggest any normative prescriptions for post-networked infrastructure or heterogenous configurations. Though there may certainly be issues around compromising meagre public budgets with costly high-tech solutions or setting standards and expectations that may not be replicable elsewhere, describing heterogeneous systems does not provide clarity as to which are better than others or under what conditions fully networked systems might be supported or abandoned. Nor does it help us discern which sorts of heterogeneity contribute to more just city-building and which do not. That an MBR plant is infused with hybrid governance and social and political practice, or that a decentralised system bypasses the material limitations of a city-wide network or the routine bureaucratic and fiscal arrangements of a city administration, should not compel us to reject and vilify, or valorise and uncritically embrace the choice of MBR technologies in service delivery.

Instead, our conclusions chime with infrastructure scholars calling for nuanced readings of contemporary urban infrastructure configurations and associated technologies. Returning to Bhan's (2019) proposition for grounded urban research, a more ambivalent approach compels us to reject simple narratives that position, for example, the network and post-network in opposition. Implicit in our findings is a similar rejection of other binaries; between failing and working; labour and mechanization; and even perhaps, between Southern experience and Northern ideals. Rather, our research supports infrastructural narration that is attentive to nuance, contradiction, even contested understandings of urban service delivery configurations, exposed through grounded inquiry.

Taking the case of Kotari and Addis at large, the MBR system allowed the state to deliver on its mandate to provide high-quality serviced housing in peripheral areas of the city, with a reasonable level of efficacy. That it is riddled with mundane blockages and issues of sustainability, particularly in the context of currency crises and limited resources, requires the state's on-going attention and openness to learning. In other words, our approach offers an understanding that is attentive both to what the MBR enables as well as challenges on the horizon, without normativity in relation to such decentralised technologies. However, at the same time, our understanding of the lived experience of human engagement with infrastructure in Southern cities, helps equip scholars to assess different technologies critically and in

propositive ways. New technologies require and enable new imaginaries for cities. The question here is not whether the MBR is good or bad, but how decentralised technologies in post-networked cities can be introduced and sustainably governed. Examination of the material infrastructure interfaces points to recognition of hybridity, acceptance of heterogeneous infrastructure configurations and inclusive coordination of multi-scalar governance. Together they might be deployed towards a very different infrastructure ideal for Addis Ababa's future.

Acknowledgements

This paper is based on the 'Governing Infrastructure Interfaces' project by LSE Cities at the London School of Economics and Political Science in partnership with the EiABC at Addis Ababa University and the African Centre for Cities, University of Cape Town. The authors would like to thank the project collaborators Philipp Rode, Zegeye Cherenet, Tilahun Derib, Biruk Terrefe, Marco Di Nunzio, Sue Parnell and Bilisaf Teferri as well as all experts and authorities that supported this work with their input. Any findings, interpretations, and conclusions presented in this article are entirely those of the authors and should not be attributed to any of the aforementioned entities or individuals.

Declaration of conflicting interests

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

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: It was supported by the *Cities & Infrastructure Programme* run by the British Academy [CI170346] on behalf of all the National Academies as part of the UK Global Challenges Research Fund.

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