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Making heterogeneous infrastructure futures in and beyond the global south

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ABSTRACT

Infrastructure has never been a single thing, understood in a universal way. Yet, there has long been a broad overarching orthodox approach in which 'experts' create replicable, stable, large, networked systems to control nature and ensure regular, predictable flows of people, materials and information. Within this orthodoxy, infrastructure is narrated as good, contributing to economic and social development. In this paper, we identify environmental, economic, political and social pressures challenging this approach to infrastructure, pushing for it to be understood, enacted and constructed differently. We then show how actors have responded to these pressures through examples of flood mitigation, corridor development and sanitation. Our cases are not pure instances of a new approach. Instead, we use them to tease out emergent efforts (and struggles) to rework infrastructure, to make it more fluid, flexible, sustainable and responsive to democratic demands, as well as to more clearly link infrastructure with well-being. These examples reinforce the importance of differentiating infrastructure, including considering how particular approaches imagine and contribute to sustainability and well-being. In this context, we

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point towards broader ideas of how infrastructure might be reimagined and remade in the future, and the difficult politics of such new visions.

1. Introduction

Infrastructure has long been seen as a 'black box' of sociomaterials that make other things flow, providing a long-term, stable and durable context for more interesting things to happen. It was seen to draw our attention primarily when it fails (Graham, 2010; Star, 1999) or inspire awe as a symbol of (state or private) technological power (Kaika & Swyngedouw, 2000; Larkin, 2013). For many generations, infrastructure in the academy was largely seen as the subject of 'experts' such as planners and engineers who would decide what was needed and where it would go. Using modern science, nature could be controlled and people's needs and wants could be met through centralised, regulated systems. These systems could be replicated, meaning infrastructure systems could be built largely along the same lines in different places. Such infrastructure was understood to be good, enabling collective goods such as public health, economic development and public services. Because of their fixed and durable nature, such infrastructures tend to promote lock-in both in ways of making/doing infrastructure but also, crucially, ways of imagining 'good' infrastructure (Egyedi & Spirsos, 2011).

This way of approaching infrastructure (which we refer to as 'orthodox') was, of course, always tenuous, partial and contested, changing over time and across spaces. Its successes varied too, and 'success' was always dependent on the identified purpose of infrastructure. There is growing attention, particularly in the global south, to the limits of this way of understanding infrastructure, even as a heuristic: in practice 'systems' rarely work as legible, knowable, and calculable. Infrastructure has contributed to economic growth, public health and the extension of services in many places, but has equally been shaped by, and contributed to, widespread inequality and unsustainability. It requires continuous maintenance and is increasingly seen as fragile and vulnerable to a range of dynamics from climate change to the vagaries of international finance. Scepticism over old ways of understanding and doing infrastructure seems increasingly prevalent, voiced even by many of those who invest in, build, govern and use them. Always fraught, these fixed infrastructures seem poorly equipped to handle an increasingly uncertain future (De Haan, 2011; Hickford et al., 2015).

In this context, the last twenty-some years have seen a burgeoning interest in opening up the 'black box' to both understand and question what infrastructure is, what it does, and who it does what for (Larkin, 2013; Star, 1999). Rather than passive material phenomena, infrastructure is instead framed as active, complexly layered sociotechnical structures shaped by knowledge and practices, social institutions, expert networks, and concerned social groups (Anand, 2017; Blok et al., 2016). Infrastructure can no longer be seen as somehow implicitly or inherently good and promoting a common set of interests. Instead, it is understood to be political, at times reflecting, embodying and perpetuating unequal and unsustainable developments (Dwyer, 2020; Rutherford, 2019). Infrastructure is no longer being left to experts who quantify, calculate, plan and build it. Instead, there has been an explosion of inquiry as to what is done in the name of infrastructure and how different imaginaries and practises of infrastructure shape different outcomes (Anand et al., 2018; McFarlane & Rutherford, 2008; Mitchell, 2014). Many have worked across the global south (and to some extent, the north) to describe infrastructures that already look and operate quite differently, demonstrating the importance of such pluralism to understanding the world that is (Jaglin, 2014; Lawhon et al., 2018). They note that infrastructure has always been heterogeneous and incomplete (Guma, 2022; Lawhon et al., 2018), experimental, at times serving as a 'test site' for patterns later deployed in the north (Van der Straeten & Hasenöhrl, 2016), and never quite lived up to its promise (Anand et al., 2018). A need for new thinking about material flows and spatial connectivity is increasingly evident (De Haan, 2011; Hickford et al., 2015; Saritas & Smith, 2011; Wakefield, 2020), exacerbated by ongoing crises ranging from the Covid-19 pandemic to climate change to geopolitical shocks like Russia's attack on Ukraine.

Despite ongoing considerations in and beyond the academy, many questions remain as to what other ways of understanding and practising infrastructure might entail, and how they might be created (Lawhon et al., 2018; Wakefield, 2020). Already-existing heterogeneous infrastructure configurations have their own constraints: they too can be unsustainable, unpredictable, and easily disrupted, are generally more labour intensive, may be inaccessible for some and risky and unsafe. These other modes of doing and thinking about infrastructure may well provide inspiration, yet it remains unclear what we might learn from the variety of approaches and cases (Baptista & Cirolia, 2022). The difficulty of displacing existing ways of understanding and creating infrastructure is, of course, in part about entrenched interests: many still benefit from particular ways of building infrastructures and have a vested interest in upholding prevailing patterns. While important, this is not the only limit: in many ways those who work with infrastructure remain 'locked in' to what is increasingly seen as an outdated way of understanding and making infrastructure, unsure of how to understand, imagine and create different infrastructural futures (Nader, 2010; Lawhon, Makina et al. 2023; Lawhon, Nakyagaba et al. 2023).

In this context, we write this paper as fourteen scholars of infrastructure, coming from different disciplines, working across more than twenty countries (primarily but not exclusively in the global south), with an eye towards the future of what infrastructure might become. We start from our shared sense of an ongoing shift in both how we think about infrastructure, and in how infrastructure is designed and built. We root our insights in our experiences in the global south, where the inconsistencies, contradictions and tensions of orthodox ways of thinking about and enacting infrastructure are often most visible, contributing to an ongoing search for new ways of thinking about and creating infrastructure, and widespread already-existing patterns and practices that defy easy categorisation. Yet our argument is not precisely *southern*, for it has resonance and relevance beyond the south (see Lawhon & Truelove, 2020). The south, then, is a place from which we might more clearly see the limits of prevailing ways of practising and thinking about infrastructure everywhere, and possibilities for different infrastructural futures.

In the next section, we provide a brief overview of infrastructure and infrastructure studies in the global south. We then identify a

set of salient pressures that are together pushing forwards a shift in how infrastructure is understood and practised, and consider how these pressures are being grappled with across a variety of sites. The shift we point to is not present everywhere, and difficult to capture in a single case, from a single perspective; we therefore draw from a series of purposively selected examples to show emergent new ways of doing and thinking about infrastructure. The examples we discuss are imperfect: they do not show us how to fully redress or transcend ongoing pressures. Instead, we use these cases to help us identify ways of thinking about, and practising, infrastructure beyond existing orthodoxy. Our contribution is not precisely to think differently about what infrastructure is: we agree with recent articulations of it as sociotechnical forms that enable and shape how goods, people and information flow. Instead, it is to articulate an orthodox mode of doing infrastructure and attend more carefully to how people are responding to its failings by doing infrastructure differently. In doing so, we begin articulating a different understanding what 'good' infrastructure is and might be, and how it might better respond to the uncertainties of the future. We call attention to these unorthodox approaches to infrastructure, and the merits of thinking from the south, with the hope of shaping the future of infrastructure, and infrastructure studies.

2. Infrastructure in the global south

In order to understand how ongoing practices and thinking differ – and what this means for the future – we first provide an overview of infrastructure that is, of course, but a partial and general sketch. Infrastructure has long been seen to be central to development, creating conditions for material flows and economic growth (Headrick, 1979). It has also long been unequal: colonial infrastructures were built largely for the extraction of resources and services were always provided unevenly (Rodney, 2018 [1972], Van der Straeten & Hasenöhrl, 2016). Scholars of India's much-lauded railroads, for example, have shown not only their role in creating a modern economy but also their connections to extraction, exploitation, hunger and disease (Tharoor, 2018; Sweeney, 2008, see also Cowen, 2020). Postcolonial governments have struggled with this fraught history, often attempting to layer, weave into and rework infrastructures towards broadly conceived projects of national development (McFarlane, 2008; Nilsson, 2006). Working within modern theories of development, they coupled spatial planning with social engineering, and sought to establish positive feedback loops between the transformation of territory and the 'improvement' of populations (importantly, social engineering initiatives were often resisted by citizens). Following both capitalist and socialist pathways, many envisioned that, with the right combination of investment, state planning and technical expertise, postcolonial countries might well follow northern development trajectories. Many postcolonial states took out loans to build infrastructure, undertaking grand projects, often as symbols of power as much as utility. Many aspired– and continue to aspire– to copy infrastructures in the same style as colonial ones, but with a wider aim of developing a nation (Colven, 2017; Lesutis, 2021).

While there are notable changes over time, here we consider common threads of an orthodox approach to infrastructure, mindful that there is not a universal, global, singular or shared way of thinking and making infrastructure. This includes a faith in expert knowledge, static and controllable ecologies, replicable systems that are externally legible and the delivery of black-boxed services to citizens. This orthodox narrative was also teleological, in which infrastructure shifted from fluid, flexible, and redundant configurations towards fixed and 'efficient' systems. Infrastructure studies often consider the durability of pre-designed physical infrastructure networks and artefacts as a key characteristic of infrastructure: the seemingly stable and long-lasting "inert" material results of past planning and design decisions "frozen in space" are part of what make infrastructure an important object of study (Graham & Marvin, 2001; Graham, 2000; Hughes, 1987). This fixity was generally considered to be good, for it provided a concrete anchor for concrete plans for the future.

In the global north, neoliberalism caused the splintering of infrastructure, fracturing the *modern* vision; infrastructure investments in the south changed in response to (often forced and coerced) structural adjustment programs (Graham & Marvin, 2001). Specifically, this meant that infrastructural narratives no longer were underpinned by assumptions of strong states and universal provision. Yet in many ways, the broader approach to infrastructure– as a means through which to control nature through expert knowledge and replicable systems– remains.

While neoliberalism is often identified as the cause for the shift away from modern infrastructural thinking in the global south, the wider vision of a strong state that could finance and guide development through investments in this orthodox type of infrastructure was always fraught (Scott, 1998). Most large-scale infrastructure was funded, at least in part, through economies tightly linked to colonial exploitation and unsustainable extraction from nature. In the global south, infrastructure has *always* been splintered, providing differentiated services to different people and places (Furlong, 2014; Jaglin, 2008; Kooy & Bakker, 2008). The extent to which there was ever a deeply held belief in the possibility of modern infrastructure for all varies across places and times, but it is increasingly clear that the global south, on the whole, could never fully and sustainably follow this path.

In the last decade, there has been a revived interest in infrastructures in the global south. Ongoing patterns look somewhat different when considering infrastructures for economic development, infrastructures for protecting people from nature, and infrastructures for providing services to citizens. In many cases, the state is increasingly taking on a more active role in guiding infrastructure for economic development, both through more classically neoliberal and state-led development. Infrastructures are being mobilised for enabling and securing of spatio(-temporal) fixes of capital in general (Carmody et al., 2022) and for the unlocking of regional assets to be integrated into global networks of trade and production in particular (Schindler & Kanai, 2021; Tups & Dannenberg, 2021). This can be seen, for example, in the current popularity of growth-oriented infrastructures such as growth corridors (Dannenberg et al., 2018), (green) energy production (Greiner et al., 2022) or the promotion of information and communication technologies for development (Ouma et al., 2019; Murphy & Carmody, 2015).

States are also taking on more direct involvement in the economy as owners of capital, transnational investors and entrepreneurs (Alami et al., 2021). In some ways, these spatial development projects are reminiscent of high-modernist planning which sought to

create and control populations in part through the built environment. Contemporary state-led development is, however, largely devoid of modernist social engineering, instead working within neoliberal frameworks that entice citizens to take up opportunities for entrepreneurialism and/or participate in community projects (Dye et al., 2022; Stokes & Lawhon., In press). This may well be seen as a positive change (high modernist planning is associated with a tremendous range of social and ecological harm, Scott, 1998), yet has also contributed to delinking infrastructural development from well-being, a point we return to below.

In terms of infrastructure for service delivery, extensive investment has been made in water, energy, waste and sanitation infrastructure. States increasingly rely on partnerships with both non-profit development organisations and for-profit enterprises (although there has also been pushback and 'remunicipalisation' of some services, McDonald & Swyngedouw, 2019). Scholars have attended to the ways services are provided, explaining how they work and ensure that materials flow despite constraints, emphasising mundane practices, material improvisation and social collaboration (Guma, 2019; Silver, 2014; Truelove & Cornea, 2021). Some of these are called 'informal' or 'alternative' infrastructures (Desai et al., 2015; Meagher, 2021), yet such labels reinforce the centrality of prevailing modes of infrastructure-making and, in practice, southern infrastructures often work across 'formal' and 'informal' or 'mainstream' and 'alternative' domains. Instead, Lawhon et al. (2018) suggest that infrastructures may be better understood as 'heterogeneous infrastructure configurations' that enable material flows (cf Jaglin, 2014). Such configurations are the most common way of accessing services in the global south, are usually more accessible, with more dynamic social and material arrangements, and entail multiple redundancies that make them less efficient but also more likely to ensure material flows despite disruptions (see, e.g. Poustie et al., 2015).

Heterogeneous infrastructure configurations emerge and operate in ways that are quite different from orthodox approaches. To access water, for example, people tinker with existing networks, manipulate metres, and/or use alternative sources for different uses: they may harvest rainwater or use water from local wells for washing and toilet flushing, hack existing pipes to access water for cooking and purchase bottled water for drinking (Schramm, 2018; Wright-Contreras et al., 2017). While many have pushed more fluid southern infrastructures along a developmentalist trajectory towards more fixity, others see this heterogeneity and fluidity as playing an important role in contemporary infrastructure configurations (Makina & Lawhon, 2022). While heterogeneity and fluidity are useful points for consideration, what makes some configurations work better (in what ways and for whom) remains unclear (Baptista & Cirolia, 2022; Lawhon et al., 2018).

In this context, we can see increasing questioning of what constitutes 'good' infrastructure, ambiguity over roles and responsibilities, and an ongoing but waning belief that (all) infrastructural development brings progress (for everyone). This is underpinned by ongoing changes and uncertainties over what infrastructure is meant to do and who infrastructure is meant to benefit. After a note on our methods (Section 3), we work to contextualise these changes (Section 4), pointing to longstanding and emergent pressures that challenge orthodox ways of doing infrastructure. We then consider examples focusing on flood mitigation in Guwahati (India), corridor development in South-Eastern Europe and Sub-Saharan Africa, and sanitation in Hanoi (Vietnam), Dar es Salaam (Tanzania) and Kampala (Uganda) that point towards new ways of doing and thinking about infrastructure in an uncertain future.

3. Methodology

This paper draws on shared thinking developed from a two-day workshop 'Making Heterogeneous Infrastructural Futures' organised by authors Dannenberg, Follmann and Lawhon in Cologne in December 2021. Participants were purposively selected by the workshop organizers to represent a range of infrastructures, countries with a particular focus on the global south and disciplines within the social sciences. Our intention was to enable focused conversations on the dynamics of infrastructure and the future across many different dynamics, allowing us to speak 'beyond the case' and towards broader patterns.

At the workshop, individuals presented 'ruminations' drawn from their empirical work in response to the workshop theme and a series of prompts. These prompts asked respondents to think about self-analysed, empirical examples of infrastructure that do not fit the modern ideal, why these infrastructures emerged, and the challenges different actors face in creating these infrastructures. At the workshop, we discussed these ruminations, and worked to frame our conversations into an argument. To analyse, conceptualize and compare in these discussions, we formed small groups focused on 'pressures' and 'responses'. We worked iteratively between these groups, ensuring that our analysis and language enabled us to link particular pressures with what actors are doing differently. The themes identified by these small groups do, surely, reflect the research interests of participants. Yet by including participants working in different disciplines, countries and infrastructures, we believe we have been able to identify many (if not all) key dynamics from the perspective of social science.

Methodologically, we draw on wider thinking on the need for more capacious types of comparison to enable theory across different kinds of spaces (Robinson, 2022). While much comparison is rooted in studying similar things across similar places, we seek to generalize about the dynamics of infrastructure rather than, for example, the prevalence of particular technologies or the role of certain actors. Thus, even though our disciplines, infrastructures and sites of study vary, this abstraction enabled us to find common themes across this diversity. In subsequent months, we chose key examples to work through in this paper, ensuring that at least one case was chosen to exemplify each pressure and response. Cases were also selected to show the relevance of our thinking across many countries and types of infrastructure. Notably, all authors agreed that the arguments we present here resonated with their own empirical work. Importantly, our claims here are not that the trends we see are 'the dominant way of doing infrastructure' globally, or even in the global south. Instead, our intention is to tease out the dynamics we see in order to help shift scholarly thinking towards what infrastructures of the future might be.

The cases we describe below are drawn from interviews and analysis of policy documents across the following projects (see Table 1 for methodological details):

Table 1
Pressures and responses to infrastructure imaginaries.

	Case study	Semi-structured qualitative interviews	Other methods
Sanitation	Hanoi, Vietnam	20 interviews with 5 professional experts; 2 residents; 5 waste and sanitation entrepreneurs, 2 ward-level politicians and administrators; 1 representative of housing cooperative; 2 international consultants; 2 utility company, 1 member of ministry	policy documents analysis (7 documents)
	Dar es Salaam, Tanzania	23 interviews with 2 members of ministry; 4 international consultants; 5 residents; 3 utility companies; 4 water vendors; 2 ward-level administrators; 2 NGOs; 1 professor	policy documents analysis (6 documents)
	Kampala, Uganda	27 in-depth interviews with households, gulper operators, institutions and community leaders	21 follow-along participant interviews; participation observation of Gulper operators for two months; policy documents analysis (7 documents)
Corridor development	Namibia	65 interviews (lodge operators, professional hunters and conservancy managers in the Zambezi region as well as tour operators and government officials in Windhoek)	household survey with 652 households were surveyed, comprising 3271 household members; business survey with 47 firms in the tourism industry; a traffic census with 1795 vehicles; policy documents analysis (11 documents)
	Tanzania	137 interviews with 60 business actors, 18 government representatives, 14 civil society representatives, 17 donor representatives, 17 smallholder farmers, 11 scientists	policy documents analysis (597 documents)
	South-Eastern Europe	8 interviews with consultancies, construction companies, NGOs and governmental representatives, planning experts	policy documents analysis; three one day workshops and feedback loops with governmental representatives from each member state
Flood mitigation	Guwahati	28 interviews with state and non-state actors involved in the planning, supervising, or maintaining flood infrastructure (including academia, civil society organisations and communities, explicitly representing localities, societies and resident welfare associations in flood-prone areas of Guwahati city)	policy documents analysis (9 documents)

- Sanitation: The study of **Hanoi's** sanitation system is part of the research project "Global suburbanisms: governance, land, and infrastructure in the 21st century" (cf. Schramm & Nguyen, 2019; Wright-Contreras et al., 2017). Work in **Dar es Salaam** was done as part of the project 'Translating urban infrastructures: adaptation and creativity in water and sanitation systems in African cities' (cf. Monstadt & Schramm, 2017; Schramm, 2018). Work in **Kampala** was done through the 'Heterogeneous Infrastructures of Cities in Uganda Project' (2015–2019) as well as the 'Examining nature-society relations through urban infrastructure' project (2019–2023) (cf Lawhon, Nakyagaba et al., 2023; Nakyagaba et al., 2021).
- Corridor development: The example from **South-Eastern Europe** stem from the project 'Understanding the Belt and Road Initiative in the Western Balkans' (2021–2022). The project focuses on regional infrastructure development. We draw on the outcomes of co-creation workshops in the context of the ESPON TEVI 2050 -Territorial Scenarios for the Danube and Adriatic Ionian Macro-regions project (2021–2022). The examples from corridors in **Eastern and Southern Africa** reflect work from the project 'Future in chains - socio-economic impacts of growth corridors' (2018–2025) and its research focus on Namibia and Tanzania.
- Flood mitigation: Our insights about **Guwahati** draw from the project 'Examining nature-society relations through urban infrastructure' (2019–2023).

We write this paper mindful of limitations that come from our positionality as a group of mostly white scholars based in European universities. This is in part a result of a workshop organised in Europe during a time of health uncertainties and travel restrictions, and our hope to be able to meet in person with follow up conversations in roughly the same time zones. Our arguments are informed by our reading and conversations with additional cases, including insights from southern scholars. We hope to evidence this point through our citations, but are also aware that reflections on broader shifts are not always part of publications. This broader limitation of representation is not only a concern of our pandemic workshop, but indicative of wider concerns with diversity in the academy. In light of the geopolitical asymmetries in academic knowledge production, we frame our efforts here as part of a broader project of thinking from the south and making space in academic writing for writing by southern authors. We also hope that it helps make space for interdisciplinary and collaborative research attentive not only to pressing global issues, but also to sensibilities of and critical effects on those under study.

4. Pressures and responses: changing understandings and practices of infrastructure

In this section, we point to three sets of often-interlinked pressures that orthodox approaches to infrastructure increasingly struggle to accommodate, suggesting a mismatch between this particular approach to infrastructure and the wider landscape (see Table 2). These pressures are global in the sense that they impact infrastructures everywhere, but land differently in different places. The struggle to respond to these pressures is present across the global north and south, but is particularly salient in the south.

This is followed by consideration of responses to these pressures. The infrastructures we describe are not systems that are directly copy-able, repeatable elsewhere, but are better seen as heterogeneous configurations that are fluid and constantly being reworked, and more easy to rework in response to uncertainty and change. Our examples are not representative of global infrastructure practice, but instead purposely chosen to highlight how various actors are grappling with the mismatch between orthodox approaches and ongoing pressures. They are not, however, models or blueprints. There is no universal, straightforward solution. Instead, we use this section to tease out themes to more clearly understand what might enable infrastructure to better respond to these pressures, and how we might differently think about, and practice, infrastructures in the future.

4.1. Increasingly uncertain socio-political ecologies

Infrastructure makes use of nature and makes nature usable for humans. Prevailing approaches to infrastructural design were long premised on a reasonably stable, gentle or at least predictable environmental system - a nature that could be tamed through infrastructures (Kaika, 2004). Infrastructures also worked to make nature invisible, meaning users may flip a switch or turn the tap to access water or electricity, never noticing the infrastructure that underpins their daily routines (Star, 1999). Infrastructural planning that considers sustainability has tended to unfold under a dominating ecological modernization paradigm with idealised and highly speculative assumptions promising technologically mediated transitions into a sustainable future (Blok et al., 2016; Kolbert, 2021).

Ongoing changes in the earth system are making it increasingly difficult to create long-term, stable infrastructures that hide socio-political ecological change. Contemporary infrastructures are subjected to increasingly severe conditions, including intensifying rainfalls, extreme winds, and rising sea levels. Severe but *knowable* conditions may well be surmountable, but increasingly *unpredictable* ecological conditions pose challenges to orthodox approaches of planners and engineers (De Block, 2016; Herder et al., 2011). For example, deluges have flooded wastewater infrastructure, resulting in releases of untreated sewerage (Jambeck et al., 2015; Vij et al., 2021), while droughts make it difficult to ensure that water flows (Robins, 2019). In both cases, orthodox infrastructures do not so much struggle with handling more or less water, but fail when those planning infrastructure are unable to determine water's movements.

In this context, while efforts to control nature have succeeded in making infrastructure work in particular moments and places, they have ultimately failed to tame nature. There is an increasing sense that 'modernity' (and 'ecomodernity') was always a distorted imaginary and therefore there is a need to rework expectations of what science- and infrastructure- can do (Kolbert, 2021; Lawhon & McCreary, 2023). New ways of thinking about and building infrastructures push back against the stable idea of 'nature' in modern thinking, instead being underpinned by increasingly complex ideas of dynamism and change. Whether through resilience thinking or green infrastructures, emergent possibilities push forward alternative ways of thinking about infrastructure (Mulligan et al., 2020;

Table 2
Pressures and responses to infrastructure imaginaries.

Pressures & responses	Socio-political ecologies	Financialisation & geopolitics	Governance configurations
Key dynamics	Efforts to control nature make infrastructure work in particular moments and places, but have ultimately failed to tame nature and often create negative spillovers.	Infrastructure is expected to be wealth-generating or wealth-extracting. Competition across states and between funders is opening new avenues for funding infrastructure.	Old arrangements worked for uniform, centralised infrastructure, but there is a need for new arrangements that can accommodate heterogeneous infrastructure.
Case	Flood mitigation in Guwahati: orthodox approaches continue, but have limited impact (e.g. integrated drain management and embankments)	Development corridors in Africa and Eastern Europe: pressures for finance, including pressures for geopolitical control, often lead to centralised plans for corridors that will enhance regional development, often relying on universalising visions of nationalist or econo-centric development	Sanitation in Dar es Salaam, Hanoi and Kampala: investment in networked sanitation (sewers) continues in some places, but a fully networked city is unaffordable and unsustainable
Response	Mobile pumps and rejuvenation of wetlands are examples of emergent approaches that accept uncertainty and work with nature.	Forms of resistance and reworking, including opposition and protest, as well as efforts to make investments responsive to wider interests.	States increasingly change rules to permit non-networked sanitation by a range of non-state actors. This means both including new stakeholders and finding ways to create regulations for diverse technologies.

Wakefield, 2020; Walsh et al., 2015).

Flood infrastructure in Guwahati usefully demonstrates these two contrasting ways of responding to longstanding and emergent issues with water. The dominant narrative reflects orthodox ideals of river control and urban flood protection measures, emphasising large scale interventions including integrated drain management and embankments surrounding the city (Follmann, 2016). There remains significant techno-optimism in infrastructural practices for flood mitigation; the city administration, for example, is planning to build a large underground reservoir to protect the entire city from urban floods.

Alongside this dominant approach, however, other measures are also used, including by state actors (city administrators, water engineers, maintenance labourers for water infrastructure, policy makers) as well as a host of non-state regime actors (citizens, civil society actors, academics, and activists). These measures include installation of mobile pump sets near water logging areas, raising the height of the newly constructed buildings (both private and commercial building), building walls from sandbags, leaving space in front of the building, rejuvenation of damaged wetlands and development of new green areas in the city periphery to reduce the pressure on the city. Mobile pumps are particularly emblematic here of the idea that infrastructure must be flexible, able to reduce water logging and discharge the rainwater from the roads to the nearby drains during heavy rainfall or tidal floods: they exemplify the need for quick responses to unpredictable flows of water. Such flexible technologies are also comparatively low-cost, reducing the operating costs of flood infrastructure for the entire city.

(see Bott & Braun, 2019, for Semarang, Indonesia).

Such technologies remain, in many instances, invisible within state policy and the main flood defence paradigm, seen as temporary measures while long term orthodox solutions are being developed. As they play an increasingly important role in responding to floods, however, we suggest there is an ongoing shift in how such infrastructures are thought about. Some actors, our work suggests, see these mobile and flexible infrastructures as better suited to the increasingly uncertain socioecological context. They are no longer conceptualised as 'temporary alternatives' while waiting for 'proper' infrastructure, but instead as integral and, perhaps even, better able to respond to an uncertain future.

4.2. Financialization and geopolitics

Particularly in the south, there have always been fraught connections between infrastructure, profit, extraction and geopolitics. Infrastructure is often funded by donors and investors rather than national budgets, and attached to a range of wider funding conditionalities (Klagge et al., 2020). These connections are taking on new forms as contemporary infrastructure projects are under rising pressure to conform to the logic of financialized development and geopolitical competition; financialization and geopolitical dynamics thus fundamentally shape what is funded and built by whom and for what purpose (Alami et al., 2021; Schindler & DiCarlo, & Paudel, 2021). As a result, infrastructure is often detached from broad notions of balanced socioeconomic development and well-being (Martin & Sunley, 2017).

Infrastructure projects are more and more expected to serve wealth-*generating* (state capitalises on infrastructures) or wealth-*extracting* (state converts infrastructures into asset classes) purposes. Their planning and operation occurs under rising economic or financialized scrutiny and along the imperatives of manifold stake- and shareholders (Furlong, 2019). The logic of financialized development is typically fundamentally at odds with wider public benefit and environmental concerns. Infrastructure configurations that do not generate immediate and extractable returns, therefore, may not be built; those that already exist may be ignored or allowed to degrade (sewers are a notable example here, see Hall & Lobina, 2009). Foreign companies, banks or even governments may have a considerable sway over decision-making procedures, with local interests losing ground (Tups & Dannenberg, 2021). More broadly, the subversion of public and environmental concerns to capital entails the risk of social decline, populist backlash as well as environmental degradation (Bear, 2017).

In this context, development corridors in Southern and Eastern Africa illustrate how emergent pressures from financialization and geopolitics translate into top-down and uneven modes of infrastructural development. A recent boom of initiatives underscores how contemporary corridors are envisioned to incorporate places, people, and resources more tightly into global networks of production and trade (Dannenberg et al., 2018). In territorial terms, these mega infrastructures connect major growth poles such as resource extraction enclaves and fertile land strips with major cities and ports (Chome et al., 2020, Müller-Mahn, 2020). In networked terms, they constitute complex actor networks including states, development agencies, and inter(-national) corporations designed to attract private capital investments as well as to mobilise escorting public funds (Hartmann et al., 2021). As such, contemporary corridors are reviving grand modernist visions of regional development "from above" (Enns & Bersaglio, 2019; Lesutis, 2021; Kalverlage et al., 2021).

Similarly, in Montenegro and Serbia, the decision-making processes on the Bar Boljare Highway and the Highway E-763 are to large extent funded through Chinese investments. Interestingly, both the Serbian as well as the Montenegrian planning systems have undergone substantial changes in the last decade, which also now allow for more flexible and infrastructure-led planning activities. Essentially, both countries introduced new scales of regulation by introducing Special Purpose Area Plans in Serbia with a competence at the national level. In Montenegro planning was delivered more centrally and local authorities were only involved in the decision-making process of the concrete route but not in the design of the project as such. This example is also illustrative of the changes that spatial planning procedures have undergone to allow the emergence of new corridors (Berisha et al., 2021). Further, they highlight that the narrative and reasons for the corridor developments are at times unclear, raising broader questions about participation and rationales for corridor developments.

However, corridor infrastructure development is rarely straightforward: from resistance to repurposing, various actors seek to redirect these corridors towards more capacious ends (Mkutu, 2022). For instance, along the SAGCOT, viral opposition among

smallholders as well as international NGOs against infrastructure investments that favour large farms has forced funders and investors to adopt a more nuanced and smallholder-friendly approach (Sulle, 2020). Along the LAPSSET, local communities are proactively "entangling" with the corridor by constructing temporary *manyattas* (small homesteads) to ensure that they cannot be rendered invisible for expected land acquisitions and related compensation payments (Aalders et al., 2021). These emergent efforts are emblematic of demands to make infrastructure live up to its old promises of enhancing social and economic development, not simply global finance.

In sum, the case of development corridors and their underpinning financial and geopolitical imperatives affirms the ongoing importance of considering infrastructure as inherently political. Infrastructure built along the powerful imperatives of territorial influence, global connectivity - and especially wealth-extraction - may well undermine broader social goals of sovereignty, well-being, and sustainable development. Indeed, the recent renaissance of development corridors showcases a widespread tendency among planners to align infrastructure projects with these new imperatives and to enforce them through "top down" planning agendas. Nevertheless, evidence of both resistance and subtle repurposing along corridors creates pressures, demanding that such projects be more attentive to the diverse needs and aspirations of affected people. In making infrastructural futures, local interests and agency can no longer be understood as external; they are instead a constitutive, always shaping what infrastructure, eventually, becomes. By understanding and implementing corridors as heterogeneous, contested configurations rather than fixed blueprints, this way of thinking may better enable a reintegration of infrastructure and broader questions of development and well-being.

4.3. Governing more heterogeneous sociotechnologies and stakeholder arrangements

Orthodox models of governance suggest a sovereign state should provide and enforce clear standards and rules to ensure safe and reliable infrastructure. This idea has always been tenuous in the global south, where infrastructure governance has always been subject at least in part to (neo)colonial interests, financial constraints, and investor interests. States also face ongoing pressure to ensure the provision of basic infrastructure despite restricted public resources and users' often very limited ability to pay. This has resulted in an emergent acceptance of a more diverse array of technologies, raising questions over how this diversity is to be governed (Jaglin, 2014). States are responding to these pressures by creating more capacious governance arrangements that may: defy notions of public and private (Truelove, 2019); challenge liberal understandings of territorial sovereignty and state development (Woods, 2022); and increasingly rely on global networks of expertise (in a context of contestation over 'experts').

New stakeholders and scales of regulation, as well as many processes that seem to sit 'outside' conventional regulatory processes, raise challenges for the governance of infrastructure (Easterling, 2014). Funders of infrastructure projects, for example, can override sovereignty by setting rules for environmental and socio-economic impact assessments (Linaweaver, 2003). The recent boom of development corridors in Africa highlights a tendency among multi-scalar actor alliances between states, international donors, and multinational firms to foreclose democratic decision making processes and to bypass interests of the wider public (Chome et al., 2020). This is, however, not always the case: local communities can also benefit from increased international attention and constitutional rights to successfully resist potentially harmful projects, such as, in Kenya, the cases of save Lamu initiative (Chome, 2020) and the Lake Turkana Wind Power Project (Greiner et al., 2022).

In parallel to expanding influence as a result of funding noted above, there is a growing sense that states must also govern a more plural set of technological arrangements. The waning belief that networked infrastructure can be provided for all citizens has pushed governments to accept, legitimise and govern configurations that were once seen as 'informal' and thus outside the purview of the state and/or illegal (and subject to punishment or erasure). This is particularly pertinent for sanitation, since citywide underground sewage networks are not only extremely costly in comparison to other infrastructure networks but also widely seen as unsustainable across the north and south (Van Vliet et al., 2010). The 2010 strategic sanitation plan for Dar es Salaam, for example, provides a decision tree for the utility to decide between sewered sanitation systems and alternatives such as dry toilets, depending on available resources and local water uses. However, public investments in Dar es Salaam's sanitation sector went almost completely into conventional, large-scale technologies in the early 2000 s. This reflects broader struggles over how to include, invest in and govern non-networked sanitation, including multi-scalar political tensions: in Tanzania, local municipalities are responsible for on-site sanitation, while the national government is responsible for networked sanitation (Monstadt & Schramm, 2017). There has been a similar process of legitimization of non-sewered sanitation in Hanoi, and more effort to uptake opportunities; entrepreneurs who handle sludge from septic tanks spread throughout the city can now legally register as small enterprises. However, such entrepreneurs often lack the means to invest in technological devices or to even transport the sludge to official dumping sites, and providers regularly break formal rules in the handling of septic tank sludge by dumping it into the environment (Schramm & Nguyen, 2019).

In Kampala, like in Hanoi and Dar es Salaam, there has been an effort to provide guidance from the state on non-networked sanitation (Lawhon, Nakyagaba et al. 2023). Here, however, there has been limited investment in expanding the sewer (Lwasa & Owens, 2018), and instead ongoing efforts to build infrastructure between toilets and treatment facilities to enable lower cost sludge management (Nakyagaba et al., 2021). To govern this increased heterogeneity, the state has created more pluralist governance arrangements: the Kampala Water and Sanitation Forum, for example, brings together actors from the state, NGOs and companies in order to develop synergies between different providers, technologies and regulations. Yet while the forum indicates growing acceptance of multiple stakeholders in infrastructural governance, ordinary citizens and their democratically elected leaders are largely absent from the forum (Nakyababa et al., 2021).

In sum, we find that rules are changing to allow for more heterogeneous infrastructure *and* more heterogeneous governance arrangements; both appear experimental and fluid, comprised of soft spaces as a means of responding to overlapping territorial spaces and functional relations (Allmendinger & Haughton, 2007). There is promise in these soft spaces for being able to respond to

uncertainty and change, yet the associated flexibility can also create opportunities for a lack of transparency and vested interests (Metzger & Schmitt, 2012). It can, in this context, be difficult to know who will benefit from infrastructure, who opposes it, and the role of the state in deciding and shaping these infrastructures. Participation and some degree of fluidity may be seen as necessary, but also raises challenges for democratic governance and decision-making (Jaglin, 2014).

In this section, we have shown that infrastructure is, and always have been, subject to pressures that shape what is built, where and why. There have, undoubtedly, for many, been benefits to the orthodox way of doing infrastructure: it has underpinned economic growth and improved the health and material well-being of many across the global north and south. But it is also increasingly clear that there are insurmountable risks and limits associated with orthodox ways of doing infrastructure. As a result, the assumption that building, expanding and improving infrastructure is necessarily *good* for development and well-being is increasingly being questioned. This is accompanied by a need to differentiate infrastructure and recognize that some types of infrastructure better respond to certain pressures, while others may well exacerbate ongoing challenges.

5. Emergent understandings for future infrastructure configurations

What might all this mean for the future of infrastructure and infrastructure studies? Here, we tease out key dynamics that emerge in these efforts to respond to pressures, pointing towards new understandings and practices. As noted above in our methodology, these are rooted in our own experiences across many different social science disciplines, research and extensive field work in more than twenty countries and from different kinds of infrastructure. While we have made an effort to read our data in conversation with wider literatures (see Section 2), we are also mindful that these are surely not the only areas of inquiry. Instead, we position them as important themes that we believe can usefully inform future infrastructure studies and practice. We see infrastructure configurations that are already more fluid than suggested by orthodox approaches and increasing awareness, acceptance, and support for this flexibility. To some extent this accords with research in the global north that urges making infrastructure more flexible and open to many different possible futures (e.g. De Haan, 2011; Egyedi & Spirso, 2011). Yet here, we also find generative possibilities of heterogeneity in enabling such flexibility. Further, while this literature has typically started from imagining different infrastructures for an uncertain future, this paper focuses on examples in which people already using and working to build and think differently. In this context, rather than thinking about how modern infrastructure might be adapted to uncertain futures, we instead foreground a different way of thinking.

Our intention in this paper is not to romanticise existing infrastructure configurations: of course, not all fluidity and heterogeneity is inherently better, and both, undoubtedly, raise many challenges. It is, instead, to insist that there is something to learn from these examples: heterogeneity and flexibility *can* work together to enable infrastructures to change and be responsive to future dynamic social, ecological, political and economic challenges. Further research is needed to tease out the particular dynamics under which this happens, in particular places, for particular infrastructures.

5.1. Reorienting with, rather than predicting and controlling, nature

The need for flexible technologies that can be quickly moved and adopted by ordinary people is particularly relevant in the context of ecological and climatic change. People do need to be able to plan and have some knowledge of established patterns, and new technologies can enable increased access to real-time information. Yet continued faith in technological fixes that can predict, control and render nature invisible are increasingly untenable. In this context, what understanding of infrastructure and infrastructure practices might contribute to more sustainable flows of people, materials and information in a dynamic and uncertain world?

Our argument here draws on those already working beyond the idea of fixes that can make infrastructures safeguarded or exempt from nature towards an understanding of what it means to live with nature, and the types of interventions that work with, rather than control it (Karpouzoglou et al., 2019). Responding to ecological pressures means more attentiveness to, and embedding of infrastructure within, nature. This is a deeper reorientation than simply adding ecosystem (dis-)services to our understanding of infrastructures (Nelson & Bigger, 2021; Wakefield, 2020) or regarding infrastructure as solutions to complex social and ecological dilemmas (the nature-based solutions debate) (Woroniecki et al., 2020). In some cases, new designs will need to be integrated with future infrastructure that allows it to operate with significantly less energy and resources. These new designs should not just be green substitutes, but rooted in understandings of nature and knowledge that better accord with the uncertain, indeterminate and dynamic world we live in. This likely means that the relations between infrastructure and nature that have been invisibilized by orthodox approaches to infrastructure become visible, and more carefully attended to by users of infrastructure. In this context, thinking through heterogeneous infrastructure configurations enables us to think of an ecological (re-)embedding in which nature becomes an integral rather than external domain to future infrastructures (Mulligan et al., 2020).

The outlined heterogeneity in our discussion of flood protection infrastructure showcases that there are already existing options, and similar dynamics can be read into our cases of sanitation. Some of these options continue to emphasise the importance of 'expertise knowledge', while others push us to think through the importance of knowledge and action by ordinary residents. For both 'experts' and residents, we see changing ideas and practices that suggest coming to terms with changing relationships with water. Infrastructures of the future, in sum, can best be built in ways that better accord with new understandings of ecology as well as the likelihood of more volatile and unpredictable ecological conditions. This means reimagining what infrastructure *can* and *ought* to do, moving away from the idea that infrastructure can and ought to control and invisibilize nature, and instead seeing infrastructure as a way of imperfectly mediating these relations.

5.2. Relinking infrastructure and well-being

With the stronger involvement of 'external partners' with their own agendas, a central question arises as to who benefits from particular infrastructure developments. Throughout the global south, it is clear that both externally funded and state-led development (and mixes of both in the form of public private partnerships) have provided highly uneven, and often contradictory, outcomes. In some cases, the political context of external funders have generated more sustainable infrastructures: international donors often have to follow clear regulations, environmental and other NGOs might put pressure on projects, and firms involved in large scale infrastructure have a reputation to lose. It is also clear that pressure from constituents can push for infrastructure to be more tightly linked to collective social goals. In this context, there is a crucial need to continue considering whether there might be emergent configurations of states, finance and users that better enable the reconnection of infrastructure, participation and well-being.

Doing so means attending carefully to ongoing and emergent scepticism about infrastructure and particularly the orthodox mode of doing infrastructure. Specifically, we mean deconstructing shiny visions, and confronting and rejecting the presumption that infrastructure is *inherently* good. Things like shared south-south learning across cases might help dispel overly simply narratives and provoke questions around benefits, risks and inequalities. A political analysis of infrastructure proposals means insisting on pushing past universalising, nationalist or econo-centric narratives that erase difference and instead clearly identifying beneficiaries, those who might be negatively impacted, and a more cautious evaluation of these impacts. It means recognizing that, at times, democracy is limited and it may be difficult, but not impossible, to reorient infrastructures that are motivated by the extraction of profits and resources. The conditions under which such reworking are being undertaken, as we described above, need careful consideration.

In this context, difficult as it is to say, there are often good reasons to reject proposals for infrastructure, particularly when such infrastructure might be unsustainable and increase social inequalities. This is not an easy statement to make, and we are particularly mindful of our positionality writing largely from outside the global south when making this statement. But one of the clearest points from our review of the literature and our own experiences is that infrastructure happens- that materials and people and information flow- even where external investments are limited. This is not to romanticise all infrastructural configurations, but instead to be mindful of its diversity and persistence, and insist on forefronting questions of well-being into infrastructure studies (Mollinga, 2001).

In sum, whether infrastructure might be beneficial is not simply a question of finance and geopolitics: these pressures often push infrastructure towards orthodox approaches that are legible, replicable and built for wealth extraction and accumulation. But there are other ways of doing infrastructure that better link what is built to benefits for a broader set of users. Creating these links is not only about understanding the flows of money and political pressures, but also considering assumptions about what infrastructure is, how it ought to be built and what its purpose is, as well as the extent to which orthodox infrastructures can be reworked, redesigned and repurposed in their making and governance.

5.3. Democratising infrastructure governance

What are the implications of this growing pressure for more complex governance of heterogeneous infrastructures? Many have, understandably, critiqued new configurations of actors and interests that have emerged in response to the pressures to expand participation in infrastructure governance (see, e.g., Ghertner, 2011). In some ways, pluralist governance might well open spaces for greater citizen participation in creating and shaping the purpose and practice of infrastructure. In some cases this pluralisation has meant that it is easier for local communities to voice their concerns. Broadening the state's understanding of infrastructure also enables already existing infrastructure configurations to be brought under state oversight, and this might well enable improved coordination and quality. At the same time, rather than being embedded into democratically constituted and contingent infrastructure practises, the softening of infrastructural design and implementation bears the risk of depoliticizing where, what, and for whom infrastructures are being deployed (Leitheiser & Follmann, 2021). For more plural governance configurations are not inherently more democratic. The complexities of power work on multiple scales, and infrastructure might then be pushed to align with the interests of, for example, development finance providers, multinational firms, local water mafias or particular entrepreneurs (see for example Miller, 2019).

More attention is needed to considerations of how and in what ways new actors and their economic interests might become more embedded, more subject to social pressures. This is not to idealise such possibilities, but instead to call attention to what might work, and how to further subject economic interests to social interests. These social interests are, of course, not monolithic, making it difficult to find ways to ensure different perspectives are incorporated into decision-making. Whose perspectives matter, and ought to matter, then become important considerations, and there is a need to ensure the prioritisation of those invested in the long term vision of a place over those with temporary and extractive interests. Widening participation, then, is not just about extending who participates, but ensuring that this widened participation is still subject to the desires and aspirations of citizens (Leitheiser & Follmann 2021). In a sense such calls have been long standing, but take on new dimensions and renewed urgency as ideas of what infrastructure is and ought to be shift and the associated rules and governance processes become less fixed.

The questions and observations we raise here are, of course, not the only ones that might matter for the future. We instead pose them as a foundation through which to think of infrastructure not as top down panacea for all things, but rather as a plane of possibility. There is scope to learn from what is happening in different places, even if such efforts are experimental and partial; given the ongoing heterogeneity of the present and uncertainty of the future, there is reason to attend more carefully to how infrastructures are built, funded, contested, used and governed in and beyond the global south. These ought not determine infrastructural futures, but instead be used to point towards key questions and considerations as scholars, practitioners and ordinary people work to build infrastructure for an uncertain future.

6. Conclusion

In the global north and to some extent the south, many are investing in new infrastructures, or working to maintain and rebuild existing infrastructures. In this paper, we have pointed to three key pressures that challenge orthodox ways of thinking about and building infrastructure. Drawing from our own research, reading and conversations at a workshop, we work to explain how many actors in different places in the act of using different infrastructures are also responding to these pressures in novel and sometimes surprising ways. Rather than investing in and continuing to build infrastructures with the idea that they are durable and fixed, some are working towards recognizing, learning from, and building infrastructures that work differently.

Through our example of flood mitigation in Guwahati, we showed that mobile pumps are increasingly being normalised not at temporary responses, but as an important coping strategy to manage uncertain water flows. This normalisation is largely invisible in state planning documents, but represents a notable shift in expectations of knowledge, expertise, and how people relate to water. Through our example of corridors in Africa and Eastern Europe, we showed the ways in which finance and geopolitics push to delink infrastructure from questions of well-being, challenging developmentalist narratives that imply all infrastructural investment is good. Foreign investment holds risks and potential, and crucial to making sense of infrastructure is to understand that plans are contested and reworked as they are grounded and enacted. Through our example of sanitation in Dar es Salaam, Hanoi and Kampala, we considered how states are changing both the rules and structures of governance in response to heterogeneity, and the difficulties associated with doing so.

Across our different cases, we can see the emergence and acceptance of heterogeneous, fluid, flexible infrastructures that have more dynamic and less predictable scalar and spatial character, many of which are longstanding configurations. Much differs between the cases, and none represent a perfect example of resolving or transcending the identified pressures. Yet we do believe that there is reason for scholars and practitioners to attend to this emergent approach to thinking about and practising infrastructure- indeed, many already are. In this context, we place our own findings within a wider shared sense of something emergent that has important implications for thinking about the future, a sense that comes from our research on many different types of infrastructures across many research sites.

The broader approach we outline here accords with much ongoing thinking about uncertain futures, including our inability to really know what the future may hold. Our argument here is not deterministic nor predictive: we have not sought to represent dominent trends, nor insist that the dynamics will see *will* be the way infrastructure unfolds in the future. It is also not an argument that claims there is as yet (or possibly ever will be) a singular new way of thinking about or practising infrastructure. The cases we discuss here do not point us towards a 'new normal', although they may well be part of a story of hope that pressured times may well lead to more careful, cautious and indeterminate approaches. Instead, we attend to these cases and associated dynamics because of their innovativeness in order to consider what we might learn as we look towards the future. We use them as grounding through which to offer a framework for thinking about such shifts and call for further attention to these dynamics, and how they operate across different places and infrastructures. By pointing towards emergent themes and questions, we hope to more clearly identify this trajectory, and consolidate commonalities while being open to exploration, experimentation and difference.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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