

Rethinking the governance of urban infrastructural transformations

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Rethinking the governance of urban infrastructural transformations: a synthesis of emerging approaches

Jochen Monstadt¹, Jonas Colen Ladeia Torrens², Mansi Jain³, Rachel M Macrorie¹ and Shaun R Smith¹

Recent urban debates on the governance of sustainability transformations have witnessed an ‘infrastructural turn’. Previously blacked-boxed, the role of infrastructures in sustainability transformations has been foregrounded by both growing academic scholarship and major investments in new infrastructural programs. How these changes are, and could be, governed remains somewhat opaque however, with traditional forms of knowledge and practices in need of urgent revision. To nuance public and academic debates, this paper synthesizes emerging approaches to the governance of transformative infrastructural change, revealing their underlying logics and potential contributions. These include appraisal of; alternative infrastructural pathways via ‘futuring’, their enactment via experimentation processes, supported by cross-domain coordination and new assessment methods. Such approaches may open new directions toward urban sustainability but also surface tensions and contradictions inherent to the governance of infrastructures.

Addresses

¹ Utrecht University, Faculty of Geosciences, Department of Human Geography and Spatial Planning, Netherlands

² Eindhoven University of Technology, Department of Industrial Engineering and Innovation Sciences, Netherlands

³ Utrecht University, Department of Population Health Sciences, Institute for Risk Assessment Sciences (IRAS), Netherlands

Corresponding author: Monstadt, Jochen (j.monstadt@uu.nl)

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Introduction

Cities and urban regions are firmly established as vantage points of societal transformations toward sustainable and resilient futures, as demonstrated by international agreements such as the Sustainable Development Goals and the

New Urban Agenda [1]. Such agreements highlight how far-reaching transformations are needed to achieve a more sustainable world and that these transformations can only be enacted through more effective urban governance approaches. Problematizing the societal need to change pervasive resource-intensive and emissions-intensive routine modes of urban development, scholars have pointed to a ‘transformative turn’ in urban studies [2,3]. This has been co-evolving with an urban ‘infrastructure turn’ [4,5] examining urban transformations through the lens of urban infrastructures and highlighting the profound complexities associated with current infrastructural solutions to contemporary urban challenges. Furthermore, urban sustainability policies often rely on ambitious infrastructural plans, targeting transformative urban change in urban energy, water, waste, mobility, and ICT systems. Urban infrastructures are thus central in imaginaries about (un) sustainable futures [5], whether as utopian visions of resource-efficient, smart and/or resilient cities, or as dystopian prospects of urban failures and escalating socio-ecological crises.

Urban infrastructures—that is, interrelated sociotechnical systems providing energy, water, waste, mobility or communication services essential to enable, sustain, or enhance urban living conditions—constitute crucial pathways toward urban futures in multiple ways: they mediate resource flows and emission pathways [6*]; enable or restrain socio-spatial cohesion and access to critical services structure the morphological layout of a city [7]; underpin economic development and competitiveness of cities [8]; and can be sources of urban vulnerability (or resilience) to natural hazards, technical disruptions and sabotage [9]. Given their embeddedness in urban processes, infrastructural transformations go far beyond technical innovation; they raise complex questions around finance and investment, governance and statehood, corporate culture and ownership, knowledge and skills, and patterns of land use. In such change processes, technical controversies unfold as political controversies: orders of governing urban life, social practices, cultural norms and values, political economies, as well as hegemonic forms of knowledge inscribed in infrastructure are renegotiated and foreclosed in technical terms [6*].

The multi-faceted relationality and embeddedness of infrastructures in material and socioeconomic structures, social practices, and urban politics mean that they impose exceptionally high requirements for transformative

knowledge. Such knowledge includes insight into how to address path dependencies and vested interests, anticipate risks and opportunities, and envision pathways to more environmentally sustainable and inclusive urban futures. Nevertheless, infrastructural futures are often envisioned and planned through linear, rational, and techno-economic approaches, which underappreciate critical dimensions inherent to urban sociotechnical transformations—for example, existing institutional complexities, the contested political nature of change and continuity, epistemic and normative uncertainties, and spatio-temporal situatedness. Insights about how these changes are, and could be, governed remains fragmented across multiple scholarly and practice communities, with siloed forms of knowledge, resources, and practices in need of improved complementarity and alignment.

To nuance public and academic debates, we survey the current scholarship on infrastructural change and synthesize emerging approaches to the governance of infrastructural change, analyzing their underlying logics and potential contributions. We address four approaches: first, appraisal of alternative infrastructural pathways via *'futuring'*, second, their enactment via *experimentation*, third, how this is supported by *cross-domain coordination*, and fourth, new methods for *assessing transformative change*. Our objective is to explain how each of these 'transformative approaches' addresses the distinct challenges of urban infrastructural change, frames transformation according to a specific rationale, and adopts a certain strategic approach for implementation. These debates, we argue, are not exclusive, but represent complementary, and sometimes overlapping, ways of conceptualizing urban sustainability transformation. We suggest that it is valuable to bring these approaches into dialog, while also engaging with the tensions and contradictions inherent to governing infrastructural change for sustainable cities.

Transforming cities through infrastructure governance

Infrastructural change has been central to social and urban studies of technology for many decades [e.g. Ref. 10]. Urban sociotechnical change differs greatly from narratives of a linear and sequential progress in which research and investments are assumed to lead to more efficient or sustainable technological trajectories. Rather, infrastructural change is as much a social, cultural, and political challenge, as it is a techno-economic issue. Scholarship on urban 'obduracy' has demonstrated that infrastructures usually develop according to established pathways, once sociotechnical regimes become deeply entrenched in the urban fabric [11]. Such path dependencies are evidenced by the sheer mass of material artifacts, sunk costs from past projects, and the embeddedness of infrastructures within the built environment, as well as by the inertia associated with required knowledge

and skills, vested interests of incumbents, institutional arrangements, and social and cultural practices [11]. The assumption is that once consolidated, infrastructures establish 'lock-ins' to sociotechnical constellations, restricting future planning choices and policy ambitions.

While path dependency and inertia may help explain the difficulties of radical infrastructural change, they downplay the dynamics and malleability of infrastructures [12] which are 'always already there, yet always an unfinished work in progress' [13, p. 365]. Accordingly, research has examined how certain actors can trigger significant urban changes by challenging dominant technical designs and established ways of knowing, using, operating and governing urban infrastructures. Much of this debate has focused on ways to promote sociotechnical 'transitions', understood as systemic 'regime' shifts enabled through strategic transition and niche management [14,15], which are increasingly driven by the societal need to address global environmental challenges such as the shift from fossil to renewable fuels, from linear waste flows to circular resource flows, and so on. This conceptualization often assumes that periods of stability are punctuated by transition periods in which technologies and related institutions experience structural change, through which new and incumbent systems compete [16].

Notwithstanding, radical shifts from old to new infrastructural systems (as often envisaged in transition literatures) seldom succeed, particularly if they require the synchronous or sequential change of essential system components that constitute a 'relational [. . .] arrangement of technology, actors, skills, knowledges, practices, cultural meanings and values, resources, money and politics' [17, p. 13]. Infrastructural change often occurs instead through incremental, intermittent, reversible, and dyssynchronous processes [18, p. 18]. Increasingly, scholarship has therefore drawn attention to infrastructural change resulting from many slow, gradual, or incremental changes [e.g. Refs. 19,20]. This is apposite, as for infrastructures to operate over long periods of time, they need to be constantly retrofitted and changed to adapt to emerging contingencies.

Furthermore, there is a need to examine the layering of 'old' and 'new' sociotechnical components of infrastructures over the extended timeframes during which components of incumbent systems persist [e.g. Refs. 20,21*]. According to this perspective, 'old' and 'new' infrastructures coexist or hybridize, and innovations do not simply result in the replacement of incumbent infrastructures and associated institutions with new ones [22]. Instead, innovations usually add to existing infrastructures and imply new forms of appropriation, interference, and conflict. Infrastructural transformations can thus be best understood as 'conjunctions of continuity and change' [21*, p. 307]. They are shaped by sociotechnical path

dependencies and concurrently evolve through their frequent (re)design, maintenance, repair, and innovation.

'Diffusionist' notions that assume infrastructure 'solutions' can be easily transferred from one place to another have therefore been increasingly questioned within urban studies [23,24]. Additionally, the notion that policies and infrastructural solutions can be designed using universal aspirations has been problematized, given that their implementation, use and outcomes depend on highly situated contexts [23,24]. Infrastructural change hardly happens in universally convergent and homogeneous ways, rather it is embedded in local contexts and shaped by situated and variegated forms of local appropriation, innovation, and contestation of infrastructural 'solutions'. Consequently, it is necessary to recognize that not only may an infrastructural solution be regarded as commonplace in one city and radical in another [25], but that there is a need to understand how infrastructural solutions are translated and adapted to the context of specific locales [23,24].

To address these complexities, a growing body of literatures in urban studies has engaged with the governance and politics of infrastructural transformations. These debates tackle the complexities of infrastructure governance, its situatedness in place-based institutional and geographical contexts, and the vested interests, path dependencies, and politics involved [26]. Similar to broader sustainability debates [27], urban infrastructure governance studies have moved beyond 'describing problems' to 'identifying solutions'. Hereby, they advocate for proactive, participative and reflexive approaches to sustainable sociotechnical change that test new policies and infrastructural solutions, integrate alternative values and sources of knowledge, coordinate siloed policy domains, and enact pathways toward more environmentally sustainable and socially equitable urban futures.

Such 'transformative approaches' can neither generate universal solutions to infrastructural problems nor provide a toolbox for a new generation of urban infrastructures. Instead, we argue, they each problematize different aspects of the governance of urban infrastructural change, potentially addressing the socio-spatial embeddedness, non-linearity and indeterminacy, and institutional complexities of infrastructural transformations. Each approach also surfaces political tensions related to the politics of urban infrastructure transformation (for example, who participates, whose knowledge counts, whose priorities are advanced) and contributes different insights as to how these tensions and contestations might be navigated. However, knowledge on how infrastructural transformations is already, and could be, governed remains somewhat dispersed across scholarly and practice communities, and across different types of formal and informal knowledges. We therefore advocate for bringing

these fragmented forms of transformative knowledge and practice into dialog to understand their potential and (mis)alignments.

Transformative approaches

In this section we outline four transformative approaches aimed at enabling the governance of more sustainable and equitable infrastructural transformations. We selected them inductively, through a literature review comprising social and urban studies of infrastructure, sustainability studies, transition studies, and, more broadly, science and technology studies (STS). Each selected approach has been widely discussed and has shifted from its original epistemologies (e.g. in the natural sciences, ecology, political science, STS, or public administration) and has been increasingly applied in the study of urban infrastructural change. Rather than being evaluative concepts, each approach makes specific claims to be 'transformative'. Table 1 synthesizes the expected contribution of each of these four approaches in terms of their conceptual origins, rationale, the urban challenge to which they respond, and their strategic approach.

Imagining infrastructural futures

Transformations in urban infrastructures are shaped by sociomaterial imaginaries, expectations and visions. Imagined, expected, or desired infrastructural futures have always been analytical foci in STS and related disciplines [28]. However, futures are also 'unpredictable, uncertain and often unknowable' [29].

Three assumptions underpin engagement with urban futures to govern sustainable infrastructural transformations. First, it has been recognized that imaginaries, narratives, and expectations of future infrastructures condition the assessment of risks and opportunities, investment and planning priorities, actors' involvement, and the targets, monitoring, and evaluation of urban projects [14,28]. Second, that 'sociotechnical imaginaries' configuring infrastructural investments, decision-making, policy, and research are often dominated by powerful incumbent actors and techno-economic solutions and pathways [30,31*]. This marginalizes the broad spectrum of knowledges and social innovations which could help redress current unsustainable path dependencies. Third, that infrastructural futures can be 'rendered actionable' by analyzing how existing practices, processes, and structures produce visions and expectations [32, p. 3]. In turn, this can open up debates on more imaginative pathways and inclusive approaches to enabling sustainable urban futures.

Expectations and visions of infrastructural futures can mediate across scales, institutional levels, times, and actor communities; they can also 'negotiate meanings and legitimacy, embed knowledge, engage publics and create relations of trust' [32, p. 3]. As such, urban 'futuring' includes a diverse array of tools and techniques including

Table 1

Comparative analysis of four approaches to the governance of infrastructural transformations

Transformative approach	Conceptual origins	Rationale	Urban challenge	Strategic approach
1 Futuring	i) Sociotechnical imaginaries ii) Sociology of expectations.	Images, narratives and expectations condition infrastructural futures.	Dominant urban imaginaries favor incumbent, techno-economic solutions and pathways.	i) Render urban futures actionable by analyzing prevailing sociotechnical imaginaries. ii) Cultivate inclusive processes to imagine diverse infrastructural pathways and solutions.
2 Experimentation	i) Sociotechnical transitions theory—strategic niche management ii) Urban climate governance experiments and urban laboratories.	Real-world experiments and experimental governance approaches contribute valuable knowledge and learning.	Uncertainty and ambiguity inherent to urban transformation processes and outcomes.	i) Protected niches/laboratories to trial innovative approaches/solutions, which can be learned from and scaled/amplified. ii) Experimental governance enables performance of plural urban futures, reconfiguring existing infrastructure systems.
3 Cross-domain coordination	i) Integrated resource management/nexus thinking. ii) Environmental policy integration.	Greater coordination of infrastructure provision, use, and governance will reduce resource use and carbon emissions.	Concern around limited coordination across urban infrastructure domains, given intersecting urban socioecological crises.	i) Gain increased understanding of multidimensional interfaces between infrastructure domains. ii) Strategically address cross-domain synergies and trade-offs, exchange knowledge across infrastructure domains, and introduce institutional and policy reform to stimulate ‘integrated’ resource governance.
4 New methods of assessment	Range of concepts emphasizing reflexive, formative, and inclusive approaches to evaluating infrastructural change.	New methods provide insight into frequently complex, non-linear, and contested sociotechnical change processes.	Insufficient understanding of the systemic character of infrastructures, or the ‘processes and pathways’ of change in infrastructure systems provided by dominant sustainability performance metrics.	Strategically apply diverse evaluative approaches in close collaboration with stakeholders to better understand infrastructural change management, and ensure change processes are more inclusive, transparent, and accountable.

qualitative and quantitative scenario planning, impact assessments, road-mapping, visioning, backcasting, anticipatory gaming, and foresight activities [33^{*}]. Collectively, these tools and techniques can: (i) assess (im) probable futures, (ii) examine multiple possible futures, (iii) help imagine plural futures, and (iv) scrutinize the performative potential of urban imaginaries [33^{*}, p. 6]. Beyond examining how such visions are constructed and mobilized, ‘techniques of futuring’ [34] seek to open up political conversations about infrastructural change through the collective design, visualization, and performance of ‘alternative’ urban futures. For example, Hajer and Pelzer analyze how a coalition of high-level energy actors was formed around an immersive multimedia exhibition envisioning how Northwest Europe could address global warming through large-scale offshore wind power. Backcasting, stakeholder consultation, immersive design, and performative ‘stagings’ were employed to help ‘break out of a policy deadlock via a joint experience of a desirable future’ [34, p. 226].

Imagining infrastructural futures as a transformative approach requires avoidance of traditional planning traps assuming linear patterns of change, including only ‘the usual suspects’, and failing to account for tensions and contestations in urban decision-making. This demands that we critically unpack prevailing urban sociotechnical imaginaries, engage with the relational dynamics of urban transformations, and explore multiple change pathways. Such an approach would seek to include diverse actor groups and perspectives, informal sources of knowledge, more exploratory ideation, and open-ended collaborative processes [31^{*}]. In this vein, Broto and Westman [31^{*}], analyzing a rich database of 400 sustainability initiatives in 225 global cities, highlight how few interventions recognize the need to incorporate plural visions of sustainable futures into urban decision-making processes. Consequently, they advocate for more radical approaches, for example, incorporating epistemologies of the South, alongside the co-production of knowledge and co-management of projects by urban dwellers, as a means to

enable empowerment and more just and equitable transformations.

Experimenting with infrastructural change

Urban experimentation addresses the uncertainty and ambiguity associated with urban transformations, promising to enable complex infrastructural change, potentiate learning and improvements, and demonstrate possibilities [35,36]. Experimentation—for example, instantiated in urban living or transition labs—involves combining interventions with observation, situatedness in real-world contexts, and a change orientation [37]. Theoretical interest has accompanied a rapid proliferation of heterogeneous and diverse experimental practices [38], though the extent to which experiments are utilized as a governance approach varies according to institutional contexts.

In academic debates on experimentation, two perspectives stand out [39^{*}]. The first, drawing on strategic niche management [15] and transition management [40], sees experimentation as a legitimate means to induce radical innovations (in market, technological, or geographical ‘niches’), which, if ‘scaled up’, could challenge dominant sociotechnical configurations. This approach often focuses on experiments happening at the margins, downplaying interactions within existing systems. However, Grin notes a shift from thinking about scaling up of marginal experiments toward experimenting at the ‘heart of the regime’ in a case in Amsterdam. Here, researchers working productively with civil servants explored potential synergies between energy and water companies, establishing pilots and facilitating learning across them, prompting a revision of central assumptions underpinning infrastructure provision [41]. Various other scaling mechanisms have been characterized [42], but calls for moving ‘beyond’ situated interventions are gaining ground [43].

The other perspective builds on urban climate governance [44,45] and urban laboratories literature [36], and highlights experiments as a distinctive means to govern urban infrastructural change. Proponents argue that establishing and maintaining experiments forces the reconfiguration of sociomaterial relationships and material flows that make up urban infrastructures, even if on limited scale [38]. Experiments can enact altered socio-spatial and sociomaterial relations, thereby advancing specific imaginaries, and they are therefore always politically inflected, creating frictions within existing systems. Laboratories become a ‘means by which governance is conducted,’ configurable in diverse ways, to serve specific purposes and interests [39^{*}]. Experiments matter if they ‘disrupt, reconfigure, and circulate’ their contexts [46]. Thus, experimentation is an ambivalent and tentative undertaking: at once utopian, in challenging some existing rules and precepts, yet, also pragmatic in abiding by others, ‘giving spatial form’ to utopian visions and creating opportunities for enacting ‘durable expression of the future’ [47, p. 359].

These perspectives highlight distinct facets of the politics of infrastructural transformations. The political facets highlight the ‘politics of niches’ around creating, selecting, and retaining particular innovations or practices by dominant institutional orders [48]. The latter centers on performing plural and contested futures which produce friction and controversy and potentiate political changes. Seeing experimentation as a transformative approach brings these two perspectives into dialog and raises questions as to how experimentation is conceived and conducted, who is included, how institutional settings condition these processes, and how experimentation may come to transform governance systems [49], and what politics are at play. Without scrutinizing these questions, the potential for experimentation to reshape urban infrastructural governance processes and planning practices will remain unrealized.

Cross-domain coordination

There is growing acknowledgment of the complexity of intersecting urban infrastructures systems and associated socioecological crises. The non-linearity of urban interventions and interdependence of different infrastructure systems poses serious problems for existing governance arrangements [50], which are commonly fragmented across distinct sectors or domains. Sectoral policies, interests, knowledge cultures, and institutional silos often spark trade-offs between different sustainability goals and sectoral interests, often leading to conflicts in urban decision-making. Moreover, incumbent sectoral systems often inadequately address ‘wicked’ sustainability challenges such as patterns of high and unsustainable resource consumption [14,25]. Such concerns have led to calls for infrastructural governance to incorporate principles of coordination and integration [50].

Cross-domain coordination as a transformative approach follows on from a rich range of academic debates. In public administration, ‘whole-of-government’ approaches have explored ways to overcome disintegration and departmentalization of governance arrangements [51]. Notions of ‘environmental policy integration’ have been widely debated in environmental and political science [52^{*}], gaining momentum in the EU in the 1990s, in the form of integrated resource management [52^{*}]. Recent debates have focused more on infrastructural organization, processes, and implications. Most prominently, ‘nexus thinking’ focuses on quantifying and optimizing the technical and material interactions between urban and sectoral domains. For instance, Cai *et al.* [53] argue that nexus thinking challenges conventional water policies by forcing water stakeholders to design and invest in technologies that also address energy and food system challenges. For nexus-thinking, the governance challenges are to attain the ‘coherence’ of policies that regulate resource flows [54], to realize and maximize ‘synergies’ and to reduce conflicts and trade-offs [55^{*}].

Multiple cities worldwide have now developed resilience strategies that mobilize cross-sectoral coordination to redress emerging urban vulnerabilities to environmental hazards, resource scarcities and so on.

Cross-domain coordination has distinct characteristics, including: (a) consensus that siloed knowledge and practice are inadequate for addressing complex sustainability challenges, (b) a shift of focus from policy and institutional coordination alone to one incorporating broader governance dimensions, such as the interaction of material flows, technical artifacts, and socioeconomic trade-offs, (c) the assumed desirability of coordinating and/or integrating policies, processes, and procedures, (d) promotion of common governance principles, and practices (collaboration, co-mechanisms, joint decision-making etc.), and (e) the pursuit of shared knowledge about the 'nexus', or interactions that connect urban infrastructural domains, and sustainability challenges.

This transformative approach advocates understanding the shifting institutional, material, economic, and political interfaces between urban domains, in a way that goes beyond simply recommending policy or institutional integration. However, a distinct gap persists between academic and policy ambitions and sociotechnical practice [54,50]. Research is needed not only to understand the 'boundary work' associated with 'relating' different urban domains and infrastructural sectors but also to reveal how sustainability challenges are currently framed according to different institutional imperatives, capacities, and interests.

Assessing infrastructural change

Assessments of infrastructural change are often based on a limited set of (often quantitative) indicators. Such indicators relate to the performance of ongoing operations or technological interventions, which are then translated into environmental metrics, for example, the reduction in energy consumption, emission reductions, and resource use. Such assessments are typically applied to interventions in particular socio-spatial contexts which seek to achieve specific infrastructural performance improvements. While assessments can help gauge progress toward achieving desired outcomes, such methods often do not rest on a comprehensive understanding of the systemic character, or the 'processes and pathways,' of change [56], that connect interventions to wider place-based, temporal, and institutional dynamics. The complexity and non-linearity of infrastructural change imply a high degree of uncertainty and indeterminacy that often cannot be captured by existing indicators. New approaches and methods capable of dealing with the complexities of sociotechnical change processes are therefore desirable.

Scholars have proposed many perspectives for assessing sociotechnical change. 'Sustainability transitions'

communities have developed evaluative frameworks that address meso or macro levels of disruptive sociotechnical change through protected 'niche innovations' [51^{*}]. These foreground the evaluation of transition programs, experimental projects [57–59], and transformative change policies [59,60^{*}]. Others propose a 'reflexive' approach to evaluation [61], that encourages learning across a group of diverse actors collectively aiming for a desired transformational goal. Some scholars use 'Theories of Change' [57,58] to articulate the assumptions of the programs they evaluate, identifying key hypotheses to be validated in program refinement. Still, others use formal protocols applied sequentially [59,60^{*},61]. Existing scholarship commonly emphasizes 'formative evaluation' or an inclusive approach, that is, evaluations done in close collaboration with diverse stakeholders either to improve policy design and implementation, or to add accountability to learning goals [58,59,60^{*},61]. For example, through case studies on the development of mobility-as-a-service projects in Finland and a specialty coffee project in Colombia, Ghosh *et al.* [62] arrived at clear lessons to be learnt on transformative innovation policy and transformative outcomes, forwarding a 'reflexive action framework' that required actors to collectively reflect on their own actions and the possible and desired consequences. Transformative outcomes, therefore, serve as a process-oriented heuristic within which to interrogate transformation processes through co-creation processes.

Assessment as a transformative approach accentuates how to co-constitute transformation processes; it can support the creation of shared visions (*via futuring*), stimulate learning from (un)successful *experimentation* and translate this into actionable knowledge, and provide insights for *cross-domain governance*. Assessments can also, however, highlight and potentially amplify institutional tensions associated within complex sociotechnical change, for example, by legitimizing evaluations and supporting urban decision-making, or by unveiling which processes and outcomes can be deemed transformative, by whom, and on what basis. It is therefore crucial to understand the context and rationale informing any evaluative framework.

Discussion and conclusion

Consensus is growing that business-as-usual practices are proving insufficient to understand, manage, and navigate urgent infrastructural sustainability transformations and to ensure that sociotechnical change processes have equitable outcomes. In this paper, we have synthesized a set of distinct, yet complementary, 'transformative approaches' to governing infrastructural change: futuring, experimentation, cross-domain coordination, and assessment. These approaches are not exclusive: they represent complementary and partially overlapping ways of understanding and enabling urban sustainability transformations. Our starting point was the shared

acknowledgement that notions of the performativity of visions and expectations, the scope for learning from experimentation, improved coordination across urban domains, and modes of assessing and evaluating socio-technical change contribute valuable insights into a particular aspect of how to govern sustainability transformation. However, individually, these approaches only address a highly selective facet of complex urban governance processes. While none of these approaches is entirely novel, they all stem from different conceptual origins and are often researched or applied in fragmented ways. Our concern is that continuing in this trajectory risks overlooking opportunities for potential knowledge sharing and the contribution of added value.

The four transformative approaches each make a particular claim as to how the governance of infrastructural change for sustainability can be enabled. The approaches promise to: (a) provide more creative and inclusive ways of imagining urban futures, to address limitations in how infrastructural futures are envisioned by incumbent actors, (b) enable innovative approaches and solutions to be tested and knowledge harnessed, to provide greater certainty in how to optimize infrastructural change processes, (c) provide greater coordination across infrastructure domains and disciplinary knowledge, given intersecting urban socioecological and sociotechnical crises, and (d) apply process-oriented evaluative approaches in close collaboration with diverse stakeholders, to better inform infrastructural governance and ensure change processes are inclusive, transparent, and accountable. Notwithstanding such promises, the transformative approaches considered in this article exhibit risks and limitations, including gaps between rhetoric and realized practice.

Crucially, none of the approaches can circumvent politics, or uncertainty; indeed, they involve inherently political processes and contingency planning. Each approach contains (implicit) claims about the knowledge politics of urban transformations, including who should initiate, design, implement, participate in, and evaluate the success of infrastructural change. When incumbent actors adopt and appropriate these approaches, they often privilege technomanagerial knowledge cultures, in ways that potentially reinforce infrastructural path dependencies and unsustainable or inequitable processes and outcomes. Scholars and practitioners alike must question claims that these approaches are ‘transformative’, and scrutinize what is to be transformed, and what will be reaffirmed or reinforced. It is crucial to understand, for example, whether escalating resource consumption is being challenged and aspects of sufficiency are addressed, who stands to benefit or lose out from infrastructural change, how power struggles between (vested) interests can be negotiated, and how new market entrants and institutions, innovative ideas, marginalized communities, and

alternative knowledges can be better included in urban decision-making.

Furthermore, the ‘situatedness’ of urban contexts—materially, institutionally, politically, economically—is crucial to each transformative approach. Governing sociotechnical change requires substantial time, money, knowledge, political support, and institutional resources, and such resources vary considerably between cities. Moreover, the fragmentation of distinct epistemic communities surrounding each approach very limiting. Common goals (e.g. opening multiple/alternative ‘futures’, or widening participation) but also conflicting priorities (e.g. incrementalist experimentation versus broader institutional reforms), are often not communicated, poorly aligned, and may conflict.

We suggest therefore that there is a need for more integrated, systematic, and critical ways of thinking about how these transformative approaches may contribute to contemporary urban debates and change practice, and where, when, and in what combination, they could enable sustainable and equitable sociotechnical change. First, we advocate bringing these transformative governance approaches and their respective knowledge communities into dialog to examine overlapping concerns, synergies, potential alignment in processes, and procedures and to highlight possible conflicting aims, objectives, and practices. Rather than disregarding other approaches, the practitioners and researchers engaged with (and specializing in) specific transformative approaches should explore how these approaches might inspire, complement, or conflict with other approaches in governing infrastructural change. Second, when applying, appropriating and combining transformative approaches to specific institutional and geographical contexts, more systematic and comparative empirical work is needed on the underlying governance capacities and capabilities needed to substantiate a ‘transformative turn’. This applies not only to different political systems with differing remit, responsiveness, reflexivity and formal procedures but also to cities in the global South where infrastructures are often built incrementally and where state authority/capacity to improve infrastructures is frequently weak and very patchy in its reach. Third, we advocate greater critical reflection to explore how shifts from substantive regulations toward more procedural governance approaches allow powerful stakeholders to use their agency to promote particular goals, and to determine which and whose interests are foregrounded, whilst marginalizing others.

Further critical *empirical* engagement with the merits, tensions, and contradictions inherent to governing infrastructural change for sustainability is thus urgently required, particularly if we are to avoid reinforcing problematic power differentials and unsustainable path

dependencies. Improving understanding of how these concepts, approaches, methods, and solutions ‘hang together’, and examining their cross-cutting synergies and trade-offs could provide important knowledge required to collectively transform our urban infrastructures toward more sustainable futures.

Conflict of interest statement

Nothing declared.

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