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PERSPECTIVE

Urban sustainability science: prospects for innovations through a system's perspective, relational and transformations' approaches

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Abstract In this perspective, we present how three initial landmark papers on urban sustainability research contributed to the larger sustainability science scholarship and paved the way for the continued development of urban sustainability research. Based on this, we propose three conceptual innovation pathways to trace the progression of urban sustainability science: First, urban sustainability from a system's perspective, meaning that urban sustainability requires integrative solutions to work in the tripled social-ecological-technological system setting. Second, urban sustainability from a (people and place) relational perspective, meaning urban sustainability is a contested and dynamic social-ecological contract of cities. As a governance mission, urban sustainability requires evidence from research that can inform coordinated action to bridge people, places, meanings, visions and ecosystems. Third, urban sustainability from a transformative science perspective, meaning that for urban sustainability to be achieved and progressed, deep transformations are required in systems, relations, policies and governance approaches. Our proposal for the future of urban sustainability science centres on emphasizing the relevance and policy applicability of systems' thinking, value and place thinking and transitions/transformations thinking as fundamental to how knowledge is co-produced by research science, policy and society and becomes actionable.

Keywords Cities · Nature-based solutions · Place · Sustainability · Systems · Transitions · Transformations

INTRODUCTION

Cities are places for social, ecological, economic and technological innovations that provide opportunity humanity and non-human species to more just, sustainable, livable and resilient futures. In the quest for how to progress and bring to policy and practice scalable urban innovations for sustainability and resilience, interdisciplinary and transdisciplinary science for understanding the human–nature nexus of cities will play a driving role (McPhearson et al. 2016a). Here, we review three landmark papers for urban sustainability, namely the articles of Folke et al. (1997), Ernston et al. (2010) and Andersson et al. (2014), to present a forward-looking perspective on the ways urban sustainability research has evolved and the system, relational and transformation perspectives needed to further advance the field.

We examine the converging issues and the different conceptual lenses these three articles propose for urban sustainability. First, all articles posit that a sustainable city is a city with a strong connection between people and urban ecosystems. Folke et al. (1997) state that "cities need productive ecosystems to exist" (p. 171). This represents one of the strongest early papers to make the case that urban planning needs to realize the importance of ecosystems for providing resources to support urban living. With this, authors developed the foundational arguments on how cities utilize vast resources beyond their boundaries, an early signal conceptualizing what is theorized later as urban land teleconnections (Seto et al. 2012). Ernston et al. (2010) provide a new lens for understanding the impacts of both urbanization processes as well as of disasters such as Hurricane Katrina from a resilience perspective, bringing forward a view on the importance of safeguarding ecosystem services at different scales for strengthening urban resilience. They ask for research prospects on "how uncertainty and ecosystem services can be integrated into the social practice of urban planning". McPhearson et al. (2015) further support and advance this perspective

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through an elaboration of different scale considerations for urban resilience: of cities and in cities. Andersson et al. (2014) posit that nature has a place in the urban mosaic and it is paramount that cities integrate in their policy agendas urban ecosystem services for delivering on climate adaptation, recreation and health. Authors develop their argument around the importance of stewardship of urban biodiversity and ecosystem services for developing urban governance structures to help cities become laboratories for innovation.

Second, all articles agree that urban ecosystems provide urban communities with multiple ecosystem services. Folke et al. strongly address the importance of ecosystems for carbon sequestration as a means to counterbalance the increasing carbon footprint of cities globally. In their research, they also assess the appropriation of ecosystems for the production of timber and food and the assimilation of waste by European Baltic cities. Ernston et al. (2010) warn that divisive narratives and worldviews that separate nature from cities may endanger the livability and resilience of them overall. This provides the conceptual ground for a coupled-systems perspective arguing for the multi-scale complexity and dynamics of urban systems (McPhearson et al. 2016b, c) as a nexus of networks (Bai et al. 2019). Andersson et al. (2014) is a foundational contribution about the importance of urban ecosystems in delivering multiple ecosystem services and safeguarding urban resilience. However, the employability of an anthropocentric focus of nature, and the universalism of the Anthropocene are neither questioned nor reflected upon, opening questions about the possibility of discounting the intrinsic value of nature in cities. All articles do not address the normativity of the concepts they propose, and on how, for example, issues of urban maladaptation (e.g. introduction of invasive species or unequal human access to ecosystem benefits) nor how ecosystem disservices can erode urban sustainability (Elmqvist et al. 2019).

Third, all articles introduce novel conceptualization innovations at the time for understanding urban sustainability and resilience. Folke et al. (1997) is one of the first articles to provide the concept of ecological footprint relating it to cities not to sectoral activities or industrial goods (but see also Odum 1975). It shows with evidence and a strong argumentation how dependent cities are on forests, land and marine ecosystems beyond their borders. Andersson et al. (2014) is a pioneering paper on explaining the multi-scale nature of cities and urban ecosystems from the lens of ecosystem services, bringing the framework of ecosystem services together with stewardship to highlight cities as socio-ecological systems. Social-ecological systems can be understood as complex human and natural systems that are intertwined, mutually dependent and interacting across scales (as originally stated in Berkes and Folke 1998 and in the most recent publication of Colding and Barthel 2019).

Cities are understood as "extreme innovation hubs" (Ernston et al. 2010, p. 2). Ernston et al. (2010) is a landmark paper for suggesting an integrated view of social and technological networks to explain urban complexity and the governance challenges it brings pointing out that "the resilience of cities should be determined by the interplay between different types of networks across spatial and temporal scales". This paper connects the understanding of cross-scale interactions and complex dynamic loops of urban systems with cities' potential for transformation and urban innovation. It lays a foundation for discussing transitions in urban governance through the use of experimentation and innovation to navigate change and understand uncertainty. These papers and their introduced concepts paved the way for interdisciplinary dialogue that broadened the spectrum of concepts and frameworks of urban sustainability.

URBAN SUSTAINABILITY PATHWAYS: INNOVATIONS IN SYSTEM'S PERSPECTIVES, PEOPLE–PLACE RELATIONS AND TRANSFORMATION PERSPECTIVES

Standing on the conceptual propositions these foundational papers generated, we consider three conceptual innovations as distinct in the way urban sustainability has been researched: from a system's perspective from a (people and place) relational perspective and from a transformative perspective.

We propose that these three perspectives shape and guide on-going and future inter- and transdisciplinary research pathways for addressing contemporary urban challenges. They build upon the original papers we reviewed in Sect. 1 and extend beyond their limitations: through considering a relational approach (people–place) and a transformational approach that progresses sustainability from a value proposition to an action agenda. Table 1 presents the three conceptual innovations and summarizes a proposed research agenda for future urban sustainability research that a number of *Ambio* contributions from 2010 until 2020 have highlighted.

A system's perspective in urban sustainability science

As cities are the primary human habitat in the Anthropocene and characterized by new types of social, governance and technological innovations, they are key to dealing with and guiding social-ecological-technological system transformations. Urban sustainability research

Table 1 Progressing research pathways for urban sustainability science as trailblazed by recent *Ambio* papers and perspectives organized across the three proposed conceptual lenses

Conceptual innovation	Progressing research pathways (in Recent *Ambio* papers)[a]
Urban sustainability from a system's perspective: *Urban sustainability requires integrative solutions to work in the tripled socio-ecological-technological system (SET) setting;* *System's Pathway in Urban Sustainability Research*	Deepen research on interrelations between SETs, including trade-offs and tipping points and how they condition urban sustainability (Seidl et al 2013; Felipe-Lucia et al. 2015; Keskitalo et al. 2016; Dade et al. 2019; Gren et al. 2019; Elliott et al. 2020),
	Broaden research on monitoring and evaluation tools/ frameworks for urban sustainability not limited to ecosystem service assessments (Satz et al. 2013; Haase et al. 2014; Donihue and Lambert 2015; Queiroz et al. 2015; Hoornweg et al. 2016; Hoang et al. 2018; Glaas et al. 2019)
	Enrich the evidence base of nature-based solutions (incl. green infrastructure) as SETs solutions for urban sustainability and climate adaptation (Mattsson et al. 2013; Baro et al. 2014; Imam and Banerjee 2016; Beery et al. 2017; Elliot et al. 2020; Hewitt et al. 2020)
	Economic assessments adopting a system's perspective (Bristow and Kennedy 2013; Wu et al. 2017; Fois et al. 2019)
	Policy and planning assessments and frameworks about urban sustainability (McPhearson et al. 2014; Frantzeskaki and Tillie 2014)
	Planetary or global urban system assessments for urban sustainability (Seitzinger et al. 2012; Hoornweg et al. 2016)
Urban sustainability from a (people and place) relational perspective: *Urban sustainability as a contested and an ever changing social-ecological contract of cities;* *Place and people pathway in urban sustainability research*	Examine the personal dimension of urban sustainability, or "inside-out sustainability" (Ives et al. 2020) and well-being (Summers et al. 2012; Cohen et al. 2016; Beery et al. 2017)
	Deepen research on bottom-up urban sustainability, unusual participating groups (e.g. youth and children) and the potential / role of communities to actively contribute to co-production and innovation for urban sustainability (Angelstam et al. 2013; Beery et al. 2017; Borgström 2019; Callaghan et al. 2020; Enqvist et al. 2020; Nordstrom and Wales 2019; Stens et al. 2016; Tengö et al. 2014)
	Broaden the cultural relational agency approaches of urban sustainability—including but not limited to cultural ecosystem services (Enqvist et al. 2020; Satz et al. 2013; Thiagarajah et al. 2015)
	Examine urban sustainability from a gender studies perspective, making women's contribution and role visible for urban sustainability (Müller et al. 2015; Cohen et al. 2016; Djoudi et al. 2016; Kawarazuka et al. 2017; Kaeser and Wilcox 2018)
	Proposed frontier research themes:
	Examine urban sustainability from a critical relational perspective incorporating social and environmental justice perspectives
Urban sustainability from a transformative science perspective: *for urban sustainability to be achieved and progressed, deep transformations are required in systems, relations, policies and governance approaches;* *transformative pathway in urban sustainability research*	Broaden experimental approaches to urban sustainability including citizen science, participatory monitoring, urban living labs, and test beds (Westley et al. 2011; Seidl et al. 2013; Kelling et al. 2015; França et al. 2019)
	Deepen and systematize co-creation and co-production scientific methods and approaches for urban sustainability (Crouzat et al. 2018; Webb et al 2018)
	Open to innovative bridging concepts and frameworks for urban sustainability transitions and transformations research like social innovation, leverage points, transformative capacity (Westley et al. 2011; Feola 2015; Abson et al. 2017; Castan Broto et al. 2019; Wolfram 2019; Ziervogel 2019; Borgström 2019),
	Proposed frontier research themes:
	Research on socio-ecological innovations that can address urban sustainability challenges (Westley et al. 2011)

[a]We have reviewed all the published papers from Ernston et al. (2010) paper until December 2020 issue of *Ambio* to ground the current propositions and to provide a different perspective on current and on-going research published about urban sustainability in the journal

pointed to the need of bolder and integrative solutions that draw on the triple-connected social-ecological-technological systems (SETS) (McPhearson et al. 2016a, b, c; McPhearson, accepted; Grimm et al. 2015) that cities are. This conceptual innovation builds upon and extends the call for conceptualization of Folke et al. (1997) for integrative solutions for urban sustainability and the understanding of Andersson et al. (2014) about thinking of cities as 'mosaics' where nature and society connect and are co-governed. Urban ecosystems are mediums to integrative solutions for urban sustainability (Bai 2016; Webb et al. 2018; Kabisch et al. 2017). Thus, achieving sustainability requires systems' thinking and an understanding of the complex feedback loops that drive change of urban SETS. In addition to a state-wide policy and strategic agenda for addressing the SDGs, cities have a role to play in devising approaches that also contribute to achieving SDGs and deal effectively with measures that improve urban sustainability and resilience (Hoornweg et al. 2016; Elmqvist et al. 2019).

Current research is applying the socio-ecological system approach, e.g. for the modelling of climate action planning (Pan et al. 2019) or lake management through citizen–government collaborations (Nagendra and Ostrom 2014). In conceptual terms, research is progressing the relational understanding of cities as SETS and includes the application of system's thinking in cities as a research guiding framework. Kremer et al. (2016) and Kabisch et al. (2016) point to this as a future direction for advancing research of urban ecosystem services and nature-based solutions in relation to urban sustainability and resilience. In the urban context, nature-based solutions can be understood as an inclusive umbrella concept that focusses on solutions to societal challenges (i.e. related to heats, droughts, flooding, need for recreation areas in dense urban environments, etc.) and which integrates established ecosystem-related frameworks such as 'urban ecosystem services' or 'green–blue infrastructure' (Kabisch et al. 2017). Elmqvist et al. (2017) in the edited work point towards the ways a system's understanding of our 'urban planet' can bridge different disciplines, advance knowledge and practice for urban sustainability and resilience. Albert et al. (2019) recently pointed to the fundamental role of urban planning and governance research in understanding the socio-ecological system dynamics and how they can inform the design and planning of nature-based solutions as means to urban sustainability. Elmqvist et al. (2019) reconceptualise sustainability and resilience from a system's perspective and their SETS understanding further informed a view on how to take on broad normative aspects of resilience and urban transformations. These are some signpost papers that illustrate how a system's perspective can be an ontological and epistemological foundation for urban sustainability research and enrich the science for cities (Childers et al. 2015).

Research pathways stemming from a system's perspective progress research on systematizing evaluation and assessment frameworks for urban sustainability, for providing evidence on nature-based solutions, as well as economic and policy assessment frameworks local as well as at planetary scale (see Table 1).

A relational perspective in urban sustainability science

Urban sustainability is progressively understood as a governance challenge and mission of cities. Addressing this challenge requires coordinated and co-created action across multiple actors, including actors from different sectors of cities, from different ethnic and cultural backgrounds as well as actors from different generations. This is the context in which the second conceptual innovation resonates: research on the relational agency perspective of urban sustainability forces a closer look on how different relations between actors, places and spaces, meanings and imaginaries are shaped and shift over time. This perspective brings interdisciplinary research to examine how spaces in cities need to be understood and examined as an interlay of narratives, meanings, histories, and cultural symbols where social and natural capital as well as social innovation manifest and are enabled to contribute to urban sustainability. Interdisciplinary research here also includes research on what constitutes actionable knowledge and how to synthesize different knowledge. This conceptual innovation regards urban sustainability as a contested and an ever changing social-ecological contract of cities, requiring new methods to curate and organize societal responses for the way urban ecosystems are managed, stewarded and transformed as regeneration projects to provide multiple ecosystem services.

In this perspective, the context of SETS is examined and unpacked for advancing research on urban sustainability. Critical interrogations through reviews of the way the concepts of urban sustainability (van der Hel 2018), urban resilience (Meerow and Newell 2016) and urban biodiversity (Guneralp et al. 2015) with concepts such as nature-based solutions showcasing the emerging research on understanding the context of SETS as a conflation of meanings, symbols, politics and visions. A review and synthesis paper, Keeler et al. (2019) demonstrates how a system's perspective can be complemented with understanding of values to nature as a mirroring context to the SETS dimensions through the lens of ecosystem services. We find that this conceptualization encapsulates what another recent research brings forward as well. For example, research on relational values of nature through

understanding how socio-ecological dynamics impact and get affected by (shifting of) senses of place informs stewardship and restoration objectives that in turn impact how SETS sustainability can be achieved in urban areas (Masterson et al. 2019; Elmqvist et al. 2019).

Research pathways stemming from a relational perspective progress research on understanding the personal and agency dynamics at play for motivating, understanding, activating urban sustainability including cultural and gender dimensions (see Table 1).

A transformative perspective in urban sustainability science

Urban sustainability research has seen a transformative turn over the past years. The third conceptual innovation entails the view that urban sustainability can only be achieved as the outcome of systemic transformations in SETS (Westley et al. 2011) through our relationships with urban ecosystems and within governance systems. The transformative turn in urban sustainability has been advocated from the climate adaptation and the (global) environmental challenge positions evidencing that through urban experimentation novel solutions to climate adaptation and sustainability are emerging and co-created (Feola 2015; Voytenko et al. 2016 p. 47; Crowe et al. 2016; Frantzeskaki and Kabisch 2016; Williams 2016; Wellstead et al. 2016; Frantzeskaki 2019). This extends the propositions of Ernston et al. (2010) and Andersson et al. (2014) for cities as laboratories that explore how to strengthen the relationships between people, places and nature. The question of how cities transform and which pathways and innovations or leverage points can trigger positive transformations for urban sustainability and resilience has ignited inter- and transdisciplinary research over the past years (Abson et al. 2017; Wolfram and Frantzeskaki 2016; Hansen and Coenen 2015; Hopkins 2017; Frantzeskaki et al. 2017; Webb et al. 2018; McPhearson et al. accepted). Bai et al. (2018) point to the need for research on urban transformation. Messerli et al. (2019, pp. 893–894) address the evidence that experimental labs produce for "novel tools and approaches" due to bringing together diverse actors and enable trans-sectoral collaborations.

New conceptual frameworks such as the SETS approach or transformative capacities have seen their rise for explaining the role of cities in achieving sustainability (Wolfram 2018). The transformative capacities of these new frameworks can be unpacked and mobilized (Castan Broto et al. 2019) but also the role of cities globally for the mainstreaming of urban sustainability solutions and approaches (McPhearson et al. 2016b). With cities being at the forefront of climate change and sustainability on the ground (Acuto 2016), research provides evidence that it is in the cities that social innovations materialize and experiments proliferate as spaces to co-create sustainable solutions. The transformative turn in urban sustainability has been recently proposed as a way to ensure socio-ecological justice and equity in cities (Ziervogel 2019). This provocation calls for an examination on the way urban nature is argued as being provided for a "greater good", such as for sustainability or climate change adaptation action plans to improve the overall environmental condition. Scholars argue that this process can sometimes be disguised with the tacit intention to tame or silence local voices in ways that deepen urban inequalities (Haase et al. 2017, Rigolon 2019).

Research pathways stemming from the transformative perspective progress research on experimentation research, systematization of co-creation and co-production approaches to urban sustainability and to innovative bridging concepts and frameworks, e.g. transformative capacity (see Table 1). These research pathways should also involve a critical perspective on the way they can inform new policies and planning to disrupt unsustainable systems of provision as well as consider for whom and to which extend are inclusive.

WHAT IS THE RESEARCH FRONTIER OF URBAN SUSTAINABILITY RESEARCH AND PRACTICE?

A shift to more pluralistic and actionable science paradigm is driving development of an urban sustainability science. We view three landmark papers of Folke et al. (1997), Ernston et al. (2010) and Andersson et al. (2014) as critical steppingstones for conceptual innovations that open the field to multiple other disciplines to bring new concepts and new approaches on board. In an emerging science of cities (Acuto et al. 2016; McPhearson et al. 2016a), we are beginning to see a system's perspective, an agency (relational) perspective and transformative perspective becoming the pathways for driving and broadening urban sustainability science in the present and in the future. Transdisciplinary researchers applying the SETS framework for transdisciplinary urban research need to also be more critical, especially for "rethinking the way in which urban expertise is organized—making it more collaborative with and for the people who are suffering diverse forms of social exclusion and ensuring that it is grounded in their lived reality" (Shrestha et al. 2015, p. 5).

Next to the three proposed research pathways, we can also see the benefits that a critical synthesis of knowledge within and across those pathways can yield, such as insights about depths of knowledge and blind spots that require new conceptualization and empirical investigation. This will further allow for cross-disciplinary collaborative

research for enriching urban sustainability research beyond conceptual refinements. From our perspective, we see the shift to actionable science paradigm engulfing all three pathways and to be a proposed mode for translating knowledge from critical and/or systematic syntheses across those pathways.

We agree with the statement of Messerli et al. (2019, p. 893) that sustainability science is a global mission and confirm that if we are to contribute to winning the battle of sustainability in cities, global urban sustainability science has to play a driving role. Scientists and global collaborative research networks (like Future Earth, NATURA, Belmont Forum to name a few) have a big role to play in this transition. Interdisciplinary journals like *Ambio* can trigger this by opening up to publications/contributions that are deepening and innovating urban sustainability science in its quest to contribute to an actionable science–policy–society interface. As a mission statement for the next 10 years, *Ambio* can aim for deeper, frontier-shaping and more actionable science also in the urban human–nature interface (cp. Söderström 2018).

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