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The Urban Impacts of Climate Change

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The urban impacts of climate change: introduction

Simon Goldhill and Georgie Fitzgibbon

Abstract: Climate change is a global phenomenon that significantly impacts urban life. Rising global temperature causes sea levels to rise, increases the number of extreme weather events such as floods, droughts, and storms, and increases the spread of tropical diseases. All these have costly impacts on cities' basic services, infrastructure, housing, human livelihoods, and health. At the same time, cities are a key contributor to climate change, as urban activities are major sources of greenhouse gas emissions. This special edition explores a range of climate change impacts in urban areas, the possibilities of adaptation and mitigation in different contexts, and the development of public participation and climate action.

Keywords: Climate change, urban, cities, adaptation, mitigation, informality, vulnerability.

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As the UN Environment Programme (UNEP) states, climate change is a global phenomenon that significantly impacts urban life. Rising global temperature causes sea levels to rise, increases the number of extreme weather events such as floods, droughts, and storms, and increases the spread of tropical diseases. All these have costly impacts on cities' basic services, infrastructure, housing, human livelihoods, and health. At the same time, cities are a key contributor to climate change, as urban activities are major sources of greenhouse gas emissions. Estimates suggest that cities are responsible for 75 per cent of global CO_2 emissions, with transport and buildings being among the largest contributors.[1]

The built environment is fundamental to many of the themes of COP26. It has a critical role to play in mitigating climate change, responsible for 39 per cent of energy-related CO_2 emissions. It is also central to building resilience against climatic extremes too late to avoid, through nature-based solutions. It is key, also, to the aspiration of building back better after COVID.

This special issue explores a range of climate change impacts in urban areas, the possibilities of adaptation and mitigation in different contexts, and the development of public participation and climate action.

In the first article Soledad Garcia Ferrari *et al.* (2021) consider strategies oriented to co-production which have contributed to providing solutions in low-income, vulnerable urban areas to meet some of the basic unmet needs, mostly in relation to providing infrastructure and services. However, such strategies have not been comprehensively explored in relation to needs exposed to climate change risks, such as flooding and droughts. This article draws on experiences in growing, vulnerable urban areas in two Latin American cities, Medellin in Colombia and Puebla in Mexico, which are experiencing increasing climate-change-driven risks. This research provides insights into the opportunities generated by co-produced strategies for climate change risk mitigation and adaptation in two different low-income, urban contexts. The article explores how addressing the relationship between power and knowledge created at a range of geographical scales and including different actors in low-income and vulnerable urban areas, can provide a useful framework to identify and implement solutions aimed at mitigating climate change risks.

Next, Xavier Lemaire (2021) focuses on cities in sub-Saharan Africa which are on the front line of climate destabilisation and migration. These cities have to deal with more intense flash floods, land degradation and erosion, droughts, and heatwaves affecting in particular the poor living in informal settlements. Strategies on how to adapt and move to more resilient cities are being designed. But the question is how

[1] UNEP, Cities and Climate Change: https://www.unep.org/explore-topics/resource-efficiency/what-we-do/cities/cities-and-climate-change

this transition can be achieved while municipalities in sub-Saharan Africa are facing such difficulties in coping with demographic growth, budget scarcity, and poor governance. Most local authorities in sub-Saharan Africa have constantly failed to address the fundamental basic needs of communities, even before the current acute environmental crisis. This article analyses the persistent urban planning bias preventing transition to sustainability, and considers emerging alternative strategic options promoting resilience and inclusivity while moving toward low-carbon cities, and how the discourse on post-COVID cities is relevant to the context of urban Africa.

Minna Sunikka-Blank *et al.* (2021) also explore African cities. Like many countries of rapid urbanisation, Ethiopia has an acute low-income housing shortage. Ethiopia's Integrated Housing Development Programme (IHDP) can be seen as an attempt to innovate low-income housing provision. Over 200,000 IHDP units have been built since 2005. Drawing from a Post Occupancy Evaluation (POE) survey in Amhara region, this article asks how the transition to high-rise has affected household practices and energy use. The POE survey shows low satisfaction among residents, despite energy access and sanitary facilities. The new built environment compromises and contradicts established cultural practices, reducing the residents' well-being compared to previous living in more informal settlements where the dwelling had direct access to outdoor space and community. This means that the residents tend to view IHDP housing as transitional, disincentivising improvements in the environment or social networks. Further, the loss of ground connection causes domestic and cultural practices to move indoors, increasing energy demand and reliance on appliances. This article argues that high-rise as the only typology for mass housing should not go unchallenged. If it is the only option, design standards should not be left open to interpretation by the developer and regulations should ensure adequate design, including dual aspect, flexibility and privacy in floor plans, and design and designation of outdoor spaces. The findings question the idea of modernisation of housing as a linear process and challenge the literature on the compact city model as *the* paradigm for sustainable cities in Southern urban practice.

The contribution by Cristian Silva (2021) outlines an approach to the analysis of interstitial spaces of urban sprawl. Such spaces are the outlying geography of metropolitan regions existing in-between developed or urbanised areas. As such, they constitute an eclectic mix of open spaces, natural areas, obsolete infrastructure, geographical restrictions, farming land, and other topographies that in their own way contribute to the city's environmental and functional performance. Despite being identified in the literature, there has been little recognition of interstitial spaces as part of the environmental sustainability of urban systems, and how they support cities in improving their resilience and adaptation capacities. Using the case of Santiago de Chile, this article highlights an environmental approach to studying the interstices and the need to examine such spaces at different scales linked to their respective environmental potentials.

Moving to Blue-Green Infrastructure, O'Donnell *et al.* (2021) argue that swales, green roofs, and wetlands play an important role in reducing vulnerability to climate change risks such as flooding, heat stress, and water shortages, while enhancing urban environments and quality of life for citizens. Understanding the perceptions that professional stakeholders have of BGI is fundamental in addressing barriers to implementation. A novel application of the Implicit Association Test (IAT) is developed to investigate and compare implicit (unconscious) perceptions of blue-green and grey infrastructure with explicit (conscious) attitudes. This is the first time an IAT about BGI has focused on professional stakeholders. Blue-green and grey infrastructure are perceived positively by the sample population. Overall, respondents implicitly and explicitly prefer BGI, and regard it as safer, tidier, more attractive, useful, valuable, and necessary. The individual positive explicit perceptions of grey infrastructure, nonetheless, suggest that integrated blue-green and grey systems may be preferable for professional stakeholders to incorporate into urban water management and climate change adaptation strategies.

In the penultimate article, Hannah Knox (2021) shows how everyday engagement with digital energy data in the face of climate change is remaking forms of public participation, in ways that are often overlooked in policy discussions about climate change and how to tackle it. This article presents the findings of ethnographic research in the UK with a network of engineers, activists, and citizens involved in developing smart energy monitoring systems and community smart grids. The article explores how everyday uses of data, material evidence, and sensory information on material and thermodynamic processes that appear in such projects, are opening up new spaces for public participation in climate change politics. Here, familiar discursive and deliberative forms of democratic participation are supplemented by what are termed *material diagnostics*—a practice of public-participation that revolves around a collective effort to unpack and rethink infrastructures as sites of climate action. Building on these findings, the article suggests that everyday digitally informed experiments with urban infrastructures have the potential to extend the kinds of political subjectivities and participatory politics that are possible, as governments seek to transition to a net-zero future.

Finally, Vanesa Castan Broto *et al.* (2021) ask what it means to look for reparative innovation for climate change adaptation. Scholars of climate urbanism have raised the conundrum that action to address the ongoing challenges of climate change in cities have distributional impacts, deepening existing inequalities. Climate change adaptation poses risks to the delivery of sustainable but also just resilience transformations. This challenge is related in part to ideas about urban innovation that dominate climate responses. In particular, disruptive innovations are directed towards the rupture of existing systems of knowledge, seeking to create new ways of looking at the problem. The emerging scholarship on climate urbanism suggests that measures to adapt to climate change in urban environments heeding a disruptive narrative have uneven impacts and too often disadvantage the most vulnerable communities. Reparative thought has influenced different debates on climate change adaptation and other issues related to social justice, from dealing with the aftermath of conflicts to engaging in reparative experiences to deal with trauma. Critical theory has also looked into reparation as a means to engage with reparative understandings of cultural objects and heritage. We argue for a focus on reparative innovation to open up alternative innovation frameworks that acknowledge existing material urban histories and engage with the multiple forms of knowledge that permeate the urban experience.

Together these articles highlight the range of impacts climate change has/will have in urban areas, and being to suggest ways forwards. This issue forms part of the British Academy's COP26 series, which aims to raise awareness of the importance of the humanities and the social sciences in understanding the complex human and social dimensions to environmental challenges and their solutions. The authors are drawn from a range of Academy programmes, including *Mid-Career Fellowships*, *Urban Infrastructures of Wellbeing*, which aims to support interdisciplinary research that explores how formal and informal infrastructures interact to affect the well-being of people in cities across the Global South, the *Sustainable Development Programme*, which funds researchers working on the UN's Sustainable Development Goals, and *Knowledge Frontiers*, which aims to enable different communities of knowledge and practice to illustrate the unique added value of international and interdisciplinary collaboration.

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Adaptation strategies for people: mitigating climate-change-related risks in low-income and informal urban communities through co-production

Soledad Garcia Ferrari, Katharina Kaesehage, Stephanie Crane De Narvaez and Amelia A. Bain

Abstract: Traditional top-down strategies to reduce climate-change-related risks have often failed to produce tangible results in vulnerable urban areas of the Global South. Approaches based on the co-production of adaptation solutions between diverse stakeholders offer promising alternative strategies. This contribution draws on our experiences in growing informal and low-income urban areas in two Latin American cities, Medellín (Colombia) and Puebla (Mexico). These communities lack adequate access to clean water and are exposed to risks related to increasingly frequent high-intensity rainfall events, making water management a key consideration for risk reduction. However, the factors driving insufficient water access and the perceptions of risks vary in each location, demonstrating the need for context-specific solutions. We explore how increasing community agency and co-creating knowledge for risk management between diverse stakeholders at a range of geographical scales can contribute to redressing existing social and environmental injustices, by identifying, implementing, and scaling up technically appropriate and culturally sustainable solutions aimed at reducing climate-change-related risks.

Keywords: Climate change, resilience, mitigation, adaptation, informal urban communities, co-production, integrated risk management, integrated water management, community agency.

Notes on the authors: see end of the article.

1. Introduction

In growing cities, issues of vulnerability, socio-spatial segregation, and inequality are aggravated by risks brought forth by climate change in communities that are exposed to a range of social, economic, and environmental strains. The challenges that such climate-change-impacted cities face require context-specific solutions that respond to the needs of the most vulnerable. Recent research demonstrates that informal urban communities in highly densified urban areas or in rural–urban peripheries especially struggle to adapt to climate-change-related risks in sustainable, affordable, and appropriate ways (Satterthwaite *et al.* 2017). In the context of the Global South, and Latin America in particular, approaches to reducing vulnerability through risk management and climate change adaptation are typically based around top-down decision-making, coupled with a lack of institutional capacities to address the accumulation of risks within low-income and informal settlements. The implementation of such 'traditional' forms of governance has yielded limited success in creating sustainable solutions in these communities. Appropriate mitigation and adaptation measures, including necessary infrastructure solutions, are difficult to implement due to resource implications, but also due to complex socio-economic, political, and institutional processes, particularly around low-income and informal settlements.

Recently, 'smart' technologies have been implemented by city authorities with the aim of creating more integrated, habitable, and sustainable cities through the application of intelligent, efficient technological strategies at a large urban scale (Barrionuevo *et al.* 2012). A wide range of 'smart city' strategies and programmes have been applied: for example, in urban transportation systems to monitor and optimise mobility; in resource management systems to optimise resource use (for example, energy, water, waste); and in governance to facilitate data management, improve institutional transparency and communication strategies, and promote citizen participation and inclusion, through a myriad of digital platforms. However, these strategies have typically been developed and implemented in a top-down manner and frequently omit a consideration of the needs of, potential impact on, or benefit to people living in informal or vulnerable communities (Greenfield 2013, Hollands 2015, Kitchin 2014). How such 'innovative' technological approaches could be leveraged to address climate-change-related risks in an inclusive way, to deliver a tangible reduction in vulnerability, is poorly understood.

Recognising the need for greater community ownership of risk reduction initiatives, theoretical discourses in the field of risk management have gradually evolved from a recognition of the importance of community-based and local-level risk management (e.g., Lavell 2003, Maskrey, 1984, 2011), to the current focus on interlinkages between building resilience and sustainable development (e.g., beginning with Wilches-Chaux, 1993), and the importance of integrated risk management and citizen participation (e.g., Sendai Framework (UNISDR 2015) and Sustainable Development Goals (UN General Assembly 2015)). These developments have begun to permeate into governance. For example, in Colombia, both the national Constitution (Asamblea Nacional Constituyente 2021) and the *Medellín 2020–2023 Municipal Development Plan* (Alcaldía de Medellín 2020) place an emphasis on citizen participation, despite varying degrees of success in implementation. In Mexico, citizen participation is promoted by the national Constitution (Cámara de Diputados 2021), but national civil protection legislation has been criticised for being too reactive and lacking integration across sectors and government levels (Alcántara-Ayala *et al.* 2019). Mexico City is leading the way in respect of integrated risk management in the country, having passed progressive legislation (PAOT 2019) creating new institutions and programmes that are intended to improve coordination between city and local-level governments, and promote a culture of risk prevention, citizen participation, and co-responsibility (Garcia Ferrari *et al.*, under review).

In this context, researchers and policymakers are requesting guidance and tools that consider not only the scientific understanding of risks on a local level, but also the capacity of citizens and community groups who live in impacted areas to adjust to and cope with the consequences of climate change (Davies *et al.* 2009, IPCC 2007, Pelling 2011). Key issues that impact local capacity to adapt to climate change include (i) differences in perceptions of risk and potential infrastructure solutions among stakeholders (from community to government); (ii) the consideration of diverse social, economic, and environmental issues, such as the different types of knowledge (formal/informal, technical/social) required to interact in defining solutions and policy implementation strategies; (iii) a dearth of financial resources; and (iv) differences in stakeholder's needs and power balance. A thorough understanding of these factors requires knowledge identification, knowledge development, and compromise at a range of power levels and across diverse actors, aimed towards the co-production of climate change adaptation strategies and sustainable infrastructure (UN-Habitat 2011). In recent years, such co-production approaches, originally developed in the public services sector, have been successfully applied to risk management (e.g., Aguilar-Barajas *et al.* 2019, Fraser 2017, López Meneses & Cañadas 2018). These approaches consider that complex problems, such as those related to extreme climate events or water justice in the context of an aggravating climate emergency, represent opportunities for solutions to be co-produced by a range of relevant stakeholders, such as community members, governments, non-governmental organisations (NGOs), and technical and/or scientific experts (Aguilar-Barajas *et al.* 2019). The co-production process is based on multifaceted knowledge sharing—through a 'dialogue of knowledges'—towards building short- and long-term capacity to maintain or rapidly return to the desired functions of the city in the face of a crisis (ibid.).

Our ongoing research in the cities of Medellín (Colombia) and Puebla (Mexico) is exploring the potential for co-produced mitigation and adaptation solutions to reduce climate-change-related risks in vulnerable informal and low-income urban areas. In particular, our research has highlighted integrated water management as a key concern in these areas, due to inadequate access to clean water, coupled with risks associated with increasingly frequent high-intensity rainfall events. As the factors driving insufficient water access and the nature and perceptions of risks vary in each location, our research seeks to identify context-specific solutions that contribute to reducing structural inequalities and risk, increasing social equity, and adapting to climate change. Further, our research is exploring how these solutions can be upscaled from the community level to a wider city context, leveraging community-informed 'smart' technologies to more effectively monitor and mitigate risks. Our approach has been rooted in understanding opportunities for co-development of 'actions' in close collaboration with local private and public sector stakeholders, to integrate multi-scale feedback-rich systems for risk monitoring and adaptation. The overarching goal of this work is to develop transdisciplinary knowledge and build capacity for policy implementation around issues of water governance, water security, integrated risk management, and co-produced water and risk management infrastructure.

This paper draws on the lessons from these transdisciplinary experiences, providing evidence on how bottom-up solutions can contribute to solving not only water access issues, but also to reducing vulnerability to climate-change-related risks and increasing the well-being of communities inhabiting informal and low-income urban areas. In this contribution we explore the following research questions:

1. How can stakeholder perceptions of climate-change-related risks in vulnerable informal and/or low-income urban areas help to identify priorities for risk mitigation and adaptation?
2. How can a 'dialogue of knowledges' between stakeholders help to co-create technically appropriate and culturally accepted water management strategies for risk mitigation and adaptation?
3. How can alternative approaches rooted in co-production between diverse stakeholders contribute to building resilience on a local level for integrated risk management via 'smart' technologies?

The following section presents an overview of key concepts serving as the theoretical framework upon which we base our analysis of case studies in Medellín and Puebla, addressing the gap between top-down governance that has failed to provide meaningful change and the need for effective solutions to manage climate-change-related risks at the local level. We first review the causes of vulnerability to climate-change-related risks in growing urban areas and the concepts of building resilience and adaptation. We then summarise the role of co-production approaches to build adaptive capacity to climate-change-related risks. Finally, we explore the potential for co-created 'smart city' solutions to increase adaptive capacity in vulnerable urban communities. In Section 3, we then outline the scope and focus of our previous and current research in Medellín and Puebla. Finally, we discuss the significance of our findings in relation to the outlined theoretical framework in Section 4.

2. Theoretical framework

2.1. Climate change vulnerability and adaptation in growing low-income and informal urban areas

Increasing urbanisation has driven the growth of low-income and informal communities in areas exposed to a range of environmental risks and climate-change-related hazards. The United Nations currently estimates that over one billion people globally live in vulnerable informal settlements, and this number increased between 2014 and 2018 (United Nations 2021). These complex areas are often affected by weak governance and limited financial capacity for research, policy development, and action. Low-income and self-built urban areas may also be shaped by development patterns that create new risks or exacerbate existing risks. These factors result in growing vulnerable populations living on land that is unsafe, under-serviced, and insufficiently safeguarded by planning policies (Baker 2013). Key issues that affect vulnerability of the urban poor include inadequate basic services (that is, water, sanitation, proper drainage, reliable transport, roads, or health services), as well as tenure insecurity, poor financial security, social networks, and ad hoc adaptation to climate change and environmental hazards (ibid.). These vulnerable communities are increasingly exposed to climate-change-related risks, such as drought or high-intensity rainfall events triggering flash flooding and landslides, yet are often least able to cope with the associated impacts because of a limited capacity to adapt (Davies *et al.* 2009, Hardoy & Romero Lankao 2011). Furthermore, weak governance and a lack of policy development contribute to shifting the focus of public sector authorities to the most pressing problems impacting these communities via short-term programmes (UN-Habitat 2011) that tend to focus on infrastructure, resources, or health challenges in isolation, and fail to integrate local human resources, knowledge, and adaptation strategies. Such developments are especially problematic in Latin American cities, which have experienced sharp urban growth and where IPCC (Intergovernmental Panel on Climate Change) scenarios forecast increasingly common extreme climate events (Magrin *et al.* 2014).

In this context, building resilience requires new strategic approaches that integrate communities into decision-making, as those directly affected by climate-change-related risks 'have the best practical knowledge' because these phenomena affect their lives and livelihoods on a regular basis (Anderson & Holcombe 2013). In addition, given the heterogeneous and unequal impacts of risk in different geographic and demographic contexts, it is critical to understand risk accumulation patterns linked to varying degrees of hazard, exposure, vulnerability, and resilience (Maskrey 2011). Within this approach, vulnerability not only refers to the extent to which a community is exposed to severe climatic events or trends, and the effects on lives and the environment, but also how these events affect the ability of communities to adapt to shocks (CARE 2014). Linking the notions of vulnerability and climate change adaptation is the concept of adaptive capacity (or adaptation capacity), defined by the IPCC as: 'The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences' (IPCC 2007: 21). Approaching vulnerability from an adaptive capacity perspective can help to better examine the 'factors that influence a system's ability to modify behaviour to better cope with external pressures, such as climate change' (Ekström *et al.* 2013). Risk management strategies that integrate the adaptive capacity of citizens and community groups living in urban areas prone to climate-change-related risks, especially in low-income and informal settlements, are therefore critical (Satterthwaite *et al.* 2017).

Pelling (2011) details a three-level framework considering adaptation as an opportunity for systemic reform and gains in terms of well-being and rights, rather than an exercise in preservation of the status quo. Pelling defines the three levels of adaptation as: (1) *resilience*, enabling stability in the face of shocks and a return to the status quo; (2) *transition*, enabling incremental social change and the exercise of existing rights; and (3) *transformation*, empowering communities with new rights claims and achieving radical change in political regimes. This framework facilitates understanding the social, cultural, and political pathways through which adaptation may be achieved, and frames adaptation as a means of redressing existing social and environmental injustices.

Addressing, minimising, monitoring, and adapting to risks also encounters challenges related to differences in the perception of risk among stakeholders (for example, between informal urban communities and public sector institutions), as well as a lack of effective options for communicating formal, informal, professional, and lay knowledge on how to mitigate and adapt to risk, in addition to a lack of clarity on the responsibilities and roles of stakeholders (Etkin & Ho 2007). Addressing these challenges in relation to climate change requires an integrated approach aimed at empowering informal urban communities in observing their environment, understanding potential strategies for risk management, and leveraging their knowledge to implement suitable adaptation strategies that respond to the specific economic, social, urban, and environmental patterns (Smith *et al.* 2020a), and thus contribute to moving beyond resilience towards adaptive transformation (Pelling 2011).

2.2. Co-production approaches to build adaptive capacity to climate-change-related risks

In the Global South, co-production initiatives have been implemented to address inadequate community service provision, and to bridge the gap between top-down public management systems and the often disadvantaged citizens accessing these services (Mitlin & Bartlett 2018). Such co-production processes have been shown to strengthen community capacities, empowering low-income and informal communities to collaborate around their needs, contest power, and negotiate with public sector authorities (Allen *et al.* 2017, Mitlin 2008, Mitlin & Bartlett 2018, Watson 2014). Following on from experiences with community-based disaster risk management during the 1980s and 1990s that included explorations of co-production, this approach is beginning to gain traction in the field of risk management (e.g., Aguilar-Barajas *et al.* 2019, Anderson & Holcombe 2013, Fraser 2017, López Meneses & Cañadas 2018, Moser & Stein 2011). These co-production approaches recognise that building resilience requires solutions that are designed and implemented based on knowledge held within different stakeholder groups (e.g., Aguilar-Barajas *et al.* 2019).

Within this alternative approach, the co-production of risk management can be achieved through the implementation of a 'dialogue of knowledges' between diverse stakeholders in a specific territory, by creating a space for knowledge exchange and conflict resolution to allow negotiated agreements and solutions to be reached (e.g., Garcia Ferrari *et al.* 2021, Smith *et al.* 2020a, 2020b, 2021). This dialogue entails placing local knowledge on a level platform with technical and scientific knowledge, allowing actors such as community representatives, government institutions, NGOs, the private sector, and academia to collaborate and co-design strategies for risk management that are culturally and technically appropriate and accepted, and therefore sustainable. This approach is especially valuable where conflicts exist between the interests of the community and those of other stakeholders, which is particularly common in informal and low-income communities, and offers promising opportunities for reducing vulnerability to climate-change-related risks.

Co-production also constitutes a method of questioning urban production processes that create social injustice and inequality (Maguire & Cartwright 2008, Stevenson & Petrescu 2016), and moves beyond concepts of user involvement and participative design to directly engage stakeholders on the principle of equal partnership (Stevenson & Petrescu 2016). This approach, where stakeholders bring a diverse range of skills and knowledge based on lived and professional experience, bridges the gap between those who produce the built environment and those who use it (Allen *et al.* 2017, Stevenson & Petrescu 2016). In line with Pelling's framework described above, co-production represents a means of altering existing relationships between actors and modifying ongoing practices, empowering communities with the notion of urban citizenship (Mitlin & Bartlett 2018), and opening up opportunities for adaptive transformation through negotiated, agreed action.

Addressing local resilience within the approach of co-production and from a perspective that understands multidimensional risk requires considering three essential elements (Brugnach *et al.* 2017):

(i) *Scale*: Addressing risk at the local scale and at the community level is particularly important as 'local risk management represents the best—and often the only—option for direct action on the most specific conditions of vulnerability, acting on the capacities and resilience built through the history and social context of a community' (Durán Vargas 2011). Communities affected by risks tend to know their territory and are better prepared to monitor threats and respond via adaptation strategies. Consequently, risk analysis for different hazards must be evaluated together with socioeconomic processes at the local level, in order to better understand vulnerability (Maskrey 1989).

(ii) *Knowledge*: The effectiveness of risk mitigation depends on the integration of multifaceted knowledge, built collaboratively between actors (Hallegatte *et al.* 2018). This approach equates local knowledge with scientific and institutional knowledge. The co-production of knowledge to identify relevant solutions at the local level has been identified as key for sustainable community development processes and must be implemented through a grassroots approach (Ekanayake 1990). Further, this element strengthens the opportunity for a 'dialogue of knowledges', in which community knowledge takes a significant role in the negotiation of mitigation strategies, and different types of experience are strengthened and complemented (Smith *et al.* 2020a).

(iii) *Power*: Vulnerable groups must be empowered to influence decision-making at the local level, using community knowledge to respond to risks, assuming an active and participatory role in risk assessment, mitigation planning, capacity building, and monitoring (Pandey & Okazaki, n.d.).

Overall, the literature suggests that co-production strategies implemented as part of community-based and local-level risk reduction initiatives should aim to achieve the following objectives:

a) Allow communities to collaborate around their needs, contest power, and negotiate (e.g., Allen et al. 2017, Mitlin 2008, Mitlin & Bartlett 2018, Watson 2014).
b) Allow communities to unlock the necessary political and economic resources to reduce their own vulnerability and manage risk (Maskrey, 1984, 2011).
c) Allow a restructuring of relations between civil society and the state (Maskrey 2011), redressing power imbalances and antagonisms (Mitlin & Bartlett 2018), bridging the gap between those who produce the built environment and those who use it (Allen *et al.* 2017, Stevenson & Petrescu 2016).
d) Place different knowledge types (for example, traditional, local, technical, academic) on a level platform (e.g., Aguilar-Barajas *et al.* 2019, Allen *et al.* 2017, Borquez *et al.* 2017, Brugnach *et al*. 2017, Maskrey, 1984, Stevenson & Petrescu 2016).
e) Ensure the sustainability of agreed mitigation or adaptation solutions by ensuring community acceptability (Maskrey 1984) as well as appropriation by local groups/organisations (Lavell 2003).
f) Allow upscaling of local-level actions to the regional scale, through partnership with public sector authorities (Maskrey 1984).
g) Ensure equitable inclusion of indigenous people through appropriate collective decision-making, multi-scalar negotiations, blended knowledge, and power-sharing structures (Brugnach *et al.* 2017).
h) Build short- and long-term capacity to maintain or rapidly return to the desired functions of the community in the face of a disturbance by implementing context-specific, acceptable, and sustainable mitigation and adaptation measures (Aguilar-Barajas *et al.* 2019).

In this regard, examples of co-production of risk and water management demonstrate that third parties, such as NGOs and academia, play a valuable role in bringing additional knowledge types to supplement that existing in the community, as well as ensuring continuity, through supporting the management and sustainability of medium- and long-term strategies.

2.3. Increasing adaptive capacity to climate-change-related risks through co-created 'smart' technologies and infrastructure

Rapid urban growth, coupled with the growing impacts of the climate crisis, has resulted in a global paradigm shift to design innovative and sustainable 'smart city' solutions (via infrastructures and services) to address these intractable problems (Bibri & Krogstie 2017). Chourabi *et al.* (2012) argue that 'smart cities' can be conceptualised as an icon of a sustainable and liveable city. However, there is a diversity of perspectives, focuses, and scopes for the strategies developed within 'smart city' approaches (see further discussion in Albino *et al*. 2015 and Chourabi *et al*. 2012), demonstrating how vague the term 'smart city' remains, both in theory and in practice. Although 'smart cities' is a contested concept that has not found an overall consensus (Angelidou 2014), the notion generally represents a new urban revolution that will successfully replace the industrial era in the organisation of cities, in terms of infrastructure provision (Picon 2015).

In addition, many climate change experts, national politicians, and city leaders have acknowledged 'smart city' infrastructure and solutions as being at the forefront of climate change action in urban contexts (Appleby 2020, Calthorpe 2011, Luque-Ayala & Marvin 2015, Moreno Pires *et al.* 2017, van der Most *et al*. 2018, White 2016). Thus, cities have attempted to implement 'smart city' technology to facilitate monitoring of and adaptation to climate change risks, as well as to capture local community knowledge. 'Smart' technology is therefore proposed as a tool to increase resilience and confront challenges from a multi-framework approach, integrating policy, communities, and technologies, based on information and communication (Chourabi *et al.* 2012, Mustapha *et al.* 2016). There is also tentative evidence that 'smart' technology should be used as an opportunity to engage with a range of actors and decision-makers at different geographical scales to enable improved responses to specific current and future community needs (Pelton & Singh 2019).

Within the above context, an understanding of how 'smart' technologies will increase the well-being of the most vulnerable citizens is still lacking, as 'smart city' initiatives tend to be implemented in a top-down manner that does not necessarily consider the needs of or benefit fto people living in low-income and informal urban areas. Critics of typical top-down 'smart city' projects argue that, within the 'triple helix' of government, knowledge production, and industry, citizens are often overlooked in policymaking as they are not seen as equal agents in the construction of resilience and in risk management (de Lange & de Waal 2013). Alternative 'smart city' approaches to resilience and risk management have therefore been proposed, such as crowdsourcing monitoring data on flooding (e.g., Frigerio *et al.* 2018), which offer the opportunity for community ownership of risk reduction initiatives through their engagement and empowerment to act on complex collective urban problems. For vulnerable communities to be more resilient to climate change risk, 'smart city' projects must recognise that citizens have to play a central role (ibid.).

Advocates of a 'smart city' approach to supporting urban communities vulnerable to climate change risks argue that providing the means for citizens to leverage technology and recognise a 'smart city's' capacity for effective change empowers citizens to be more resilient and adapt to risk more effectively (Lytras & Visvizi 2020). However, although previous studies have shown that urban communities can effectively minimise, manage, and adapt to environmental risks (Hill & Martinez-Diaz 2020), these findings are limited to communities that use one specific technology and/or solution, such as renewable energy or a community currency. Research on community adaptation to climate-change-related risks through creating empowerment across geographical scales and a variety of climate change impacts is still lacking.

For vulnerable urban communities, the challenge of adaptation to climate-change-related risks is partly related to the need for more complex information-sharing that integrates feedback-rich systems across multiple actors throughout society. Experiences with 'smart city' technologies have shown that technical knowledge is only one part of the solution. A greater challenge lies in such technologies, as well as the knowledge and communication that they provide and require, being accepted, understood, and legitimised, in order for appropriate courses of action to be identified and implemented to increase resilience. Achieving this technology usage, applicability, and impact, particularly in informal areas, requires a better understanding of the needs and capacities of informal urban communities in relation to climate change risks, and the co-production of adaptive actions between communities and public sector actors (Albino *et al.* 2015). The challenges faced by the concept of 'smart cities' therefore reflect a need for context-specific solutions and actions, but also offer excellent potential for knowledge upscaling, allowing impact and risk reduction beyond the neighbourhood scale.

3. Research methodology: co-producing solutions to climate-change-related risks in low-income and informal urban communities in Medellín (Colombia) and Puebla (Mexico)

Through our work in the cities of Medellín and Puebla, we have developed participatory action research methodologies to understand perceptions of risk and stakeholder priorities in terms of risk management, as well as appropriate and sustainable mitigation and adaptation solutions, in low-income and informal urban areas in Latin America (Table 1). This research led to the identification and pilot testing of co-produced monitoring, mitigation, and adaptation strategies for environmental risks, which are aggravated by climate change. In Medellín, these efforts focused on co-created action to monitor and mitigate landslide risk in informal neighbourhoods, including 'smart' communication to facilitate knowledge exchange and increase adaptive capacity. In Puebla, the focus was on 'smart' technology for sharing knowledge and adaptation solutions to climate change risks in relation to water management at the urban–rural edge of a growing metropolitan area. In these case studies, the research explored the diverse perceptions of climate-change-related risks

Table 1. Summary of action–research methodologies applied in the completed research phases in Medellín and Puebla (ongoing work continues in these cities, see text for further details).

	SUMMARY OF ACTION-RESEARCH METHODOLOGIES		
	Research Phase & Neighbourhoods	**Research Method**	**Description**
MEDELLÍN, COLOMBIA	**Phase 1: 2016-17** "Resilience or resistance? Negotiated mitigation of landslide risks in informal settlements in Medellín" (see Smith et al., 2020a; 2020b) Initial case study community: Pinares de Oriente, Comuna 8, Medellín	**Objective 1: Understand local perceptions of risk**	
		Focus groups with residents and community leaders	2 focus groups (total around 50 participants)
		Semi-structured interviews with residents and community leaders	16 interviews
		Semi-structured interviews with key stakeholders in the public sector	6 interviews
		Workshops with third sector actors	
		Objective 2: Pilot participatory monitoring and mitigation strategies	
		Transect walks and participatory mapping exercise with residents to identify critical monitoring points	
		Training of community members to record signs of slope instability using mobile phone photography and WhatsApp groups	Preparation of a detailed guidance manual, including monitoring points, frequency of observations and safety conditions; workshop; and field walk.
		Regular monitoring of selected critical points by community members; information reviewed by academic/technical team	Community-based researchers collected data and uploaded it to WhatsApp groups during the rainy season (May-October 2017)
		Technical survey of the area, including land and housing, to identify potential interventions for mitigation of landslide risk	
		Training of community members and implementation of appropriate technical solutions, in collaboration with architecture and geology/geotechnical research team experts, to mitigate landslide risk in the neighbourhood	Mitigation works carried out by the community at the level of individual households, lanes and streets, with a focus on benefitting the community as a whole (September-October 2017)
		Evaluation workshops with the community-based monitoring team, academic/technical team, and public and third sector agencies, to assess the success of the pilot monitoring and mitigation schemes and aspects to be optimised.	2 workshops (total around 50 participants)
		Objective 3: Explore the potential for negotiated strategic landslide risk management between the community and public-sector actors	
		Joint workshops between community members/leaders, public sector and third sector actors, to reflect on the project findings and identify ways forward for, and hindrances to, institutional mechanisms to facilitate agreement and joint action between the stakeholders involved in risk management and mitigation strategy-building and implementation at different scales	Bi-lateral and multi-stakelhoder (open) meetings; a multi-stakeholder working group was also set up to determine a future risk reduction strategy at the local level, as well as potential larger infrastructure intervention with possible municipal financing - the group includes: community representatives; the municipal Planning Department (DAP); Disaster-Risk Management Department (DAGRD); Social Housing Institute (ISVIMED); and the Urban Development Company (EDU).
	Phase 2: 2017-19 "Co-production of landslide risk management strategies through development of community-based infrastructure in Latin American cities" (see Smith et al., 2020b; 2021) Expansion of methodology to two additional communities: El Pacífico (Comuna 8) and Carpinelo 2 (Comuna 1), Medellín	**Component 1: Understanding local perceptions of risk**	
		Semi-structured interviews with community residents and leaders	13 interviews in El Pacífico; 19 interviews in Carpinelo 2
		Semi-structured interviews with government representatives, NGOs and local academic institutions	Interviews with: Municipal Planning Department (DAP); Municipal Disaster Risk Management Department (DAGRD); Social Housing Institute (ISVIMED); Urban Development Company (EDU); NGOs Con-Vivamos and Corporación Montanoa; Colegio Mayor de Antioquia.
		Component 2: Community-based monitoring of landslide risks	
		Transect walks and participatory mapping workshop to identify monitoring points in each neighbourhood	5 monitoring points in El Pacífico; 6 monitoring points in Carpinelo 2
		Training of community volunteers to monitoring critical points using mobile phones	1 workshop in El Pacífico (around 20 participants); 1 workshop in Carpinelo 2 (around 15 participants)
		Regular monitoring of selected critical points by community members; information reviewed by academic/technical team	Community-based researchers collected data and uploaded it to WhatsApp groups during the rainy season (August-October 2018)
		Workshops for qualitative analysis of photographs, held with community volunteers, facilitated by the research teams	2 workshops in El Pacífico (around 25 participants in each); 2 workshops in Carpinelo 2 (around 20 participants in each)
		Final evaluation workshops with the community volunteers, facilitated by the research teams	1 workshop in El Pacífico (around 25 participants); 1 workshop in Carpinelo 2 (around 20 participants)
		Component 3: Community-managed mitigation	
		Joint identification between community members and research team of appropriate future strategies for risk mitigation in each neighbourhood; Stakeholder mapping.	Co-produced mitigation strategy document.
		Component 4: Agreement seeking and strategy building	
		Open public meetings (*cabildos*) held in 2017 and 2018, attended by community members and local government representatives, on the theme of risk management and integrated neighbourhood improvement.	Attended by over 600 residents.

PUEBLA, MEXICO	**Phase 1: 2019** 'Developing collaborative smart city solutions to manage adaptation and monitoring climate change related risks in Mexico' San Andrés Cholula	**Objective 1: Understand perceptions of climate change-related risks**	
		Focus groups with community members	6 focus groups (around 12 participants in each)
		Focus groups with local government representatives, private sector actors and NGOs	4 focus group (average of 8 participants in each)
		Site visits	
		Interviews with local government representatives	3 interviews
		Objective 2: Co-create actions to mitigate climate change-related risks	
		Community-led capacity building workshops on urban planning and citizen participation	5 workshops (around 12 participants in each)
		Workshops with community members on planning tools and guidelines	4 workshops (around 12 participants in each)
		Presentation and validation of research findings and action co-creation workshops with community members, government representatives, technical experts and academia	3 worshops (around 20 participants in each)
		Preparation of educational infographic materials and dissemination of research findings via social media	

across stakeholders, and the potential actions and solutions that could be agreed at the neighbourhood scale and later replicated across wider urban areas.

3.1. Co-produced strategies for managing landslide risk in Medellín, Colombia

An estimated 44,600 households within informal communities are exposed to the risk of landslides in the Medellín Metropolitan Area (Smith *et al.* 2020a). This number is expected to rise by at least 13,000 by 2030 (URBAM & Harvard Design School 2012). The risk to inhabitants of these areas created by informal development practices became clear in 1987, when a landslide killed over 500 people in the low-income community of Villatina, substantially contributing to the estimated 784 deaths of low-income residents due landslides in Medellín over the last eighty years (O'Shea 2014). Despite the increased awareness of landslide risk caused by this event and the subsequent plan by the city administration to relocate parts of informal communities, local residents resisted relocation. This resistance evidenced a lack of trust in institutions, fuelled by a perception of double standards towards informally settled areas, with a refusal of city authorities to invest in risk mitigation infrastructure in these areas, contrasting with a willingness to build different types of infrastructure for the benefit of either the state or private companies. This distrust was also heightened by the possible influence of armed groups behind much of the informal land allocation.

Research phase 1: initial pilot study community

Initial research in Medellín focused on the development of co-produced solutions to monitor and mitigate landslide risk in informal communities at the urban–rural city edge (Smith *et al.* 2020a, 2020b, 2021). The research took place in the Pinares de Oriente neighbourhood, within Comuna 8, one of the low-income districts located high above the city in the north-eastern sector, where largely self-built communities have grown on steep slopes. In this neighbourhood, 180 households occupy 1.52 hectares of land, with 80 per cent of these having arrived following displacement due to the internal armed conflict in Colombia. The community straddles the notional urban edge according to the city's development plan, with the area north of the boundary exposed to high and non-mitigatable risk of landslides, according to the classification by the local planning authority. A seasonal stream that runs down the steep hillside disappears under the self-built houses, and there is generally very poor management of water runoff and drainage. As a result, many homes are exposed to the risk of landslides, exacerbated by poor water management and increasingly frequent high-intensity rainfall events driven by climate change (Aristizábal Giraldo *et al.* 2020).

The pilot study in Pinares de Oriente was led by a multidisciplinary team of researchers, including expertise from sociology, planning and slum upgrading, geotechnical and environmental engineering, as well as architecture and construction. This collaboration allowed for a structured dialogue between academics, local government, and informal urban communities, with the overall aim of exploring the scope for, and acceptability of, landslide risk-reduction strategies from the community and state perspectives. The research objectives were to (a) investigate the perceptions of risk and landslide risk among the community and public-sector organisations; (b) pilot participatory monitoring and mitigation strategies in the case study community; and (c) explore the potential for negotiated strategic landslide risk management between the community and public sector actors.

This research phase involved around seventy households, participating through focus groups, interviews, and workshops (Table 1; Medellín, Phase 1). A series of interviews with households were carried out to understand their perceptions of landslide risk, which was initially denied by local residents, due to fear of eviction. Through the project, the community's stance shifted from denying risk to admitting concern, especially during heavy rain. Through engagement with the community, trust was built between the research team and those involved from the local neighbourhood, which led to the achieved openness and willingness to engage in participatory monitoring and mitigation of risk.

Through a survey of the community and the hillside above it, transect walks together with members of the community, and a participatory mapping exercise, fourteen critical points for monitoring were identified, mainly in relation to water courses and embankments, as well as underbuilds below houses. Community volunteers agreed to monitor the selected critical points, to which aim the research team prepared a simple guidance manual. Each point was monitored by a pair of volunteers, who agreed to take photographs at those points on a regular basis, following the guidance, and to send the photographs to a WhatsApp group set up for each critical point.

The research team also studied the factors impacting landslide risk to identify key mitigation works that could be undertaken by the community using appropriate technical solutions. This mitigation focused on the risk of small landslides within the community, rather than large-scale land movement that would require major engineering—or even relocation. The mitigation works focused on managing rainwater infiltration (a major factor in triggering landslides on the hillsides surrounding Medellín) and interventions were aimed around shared spaces, to ensure benefit for the whole community. The mitigation work was structured around a range of geographical scales and the corresponding levels of responsibility based on landownership around the intervention areas: a) community groups focused on the spaces around common access pathways (which are the responsibility of the local authority); b) groups of homeowners focused on spaces around groups of houses, where often inaccessible space is created due to informal construction; and c) individual homeowners focused on their own dwellings. The objective of these works was to channel rainwater towards the lower areas of the community, which are serviced by a municipality-owned drainage system, adding a fourth scale of responsibility and connecting the interventions across the community to the public network.

Regarding the use of smart technology, the research identified that an indispensable aspect of the success of the community-based monitoring methodology was having designated community leaders on the ground who motivated and encouraged residents to continue uploading digital photographs to the WhatsApp groups. The leaders sent messages on a regular basis via WhatsApp, strengthening participation and thanking people when they posted or added a photograph. Whilst digital technology helped to connect the research team with the community and facilitated a methodology for monitoring with precision, the social connections *in situ* remained fundamental for the successful application of the technology.

The research found that (1) community-based monitoring of landslide risk can be effective, but requires an ongoing and close link between the participating residents and the research team; (2) there is a need for local researchers and community leaders who are able to visit the area regularly and discuss the practicalities of data collection with the participants, as this provides 'a face' on the ground; (3) it is necessary to share with participants how the information is used and analysed across the involved national and international academic institutions to build trust; and (4) although the researchers and community members agreed upon the scale and ambition of the monitoring points, it proved to be challenging for community volunteers to cover all of these points on a regular basis, with some critical points receiving much lower attention than others, depending on the availability and interest of those undertaking the monitoring exercise (Smith *et al.* 2020b). In terms of capacity building, rooted in the experiences and approach of the research project, the local NGO ConVivamos created a Hillside Neighbourhood School (*Escuela de Barrios de Ladera*) at the wider scale of Comuna 8, in collaboration with community leaders. The school was opened to all residents and focused on sharing knowledge around landslide risks, as well as monitoring, mitigation, and adaptation actions.

This initial example of community-based monitoring of landslide risk in Medellín raised awareness among the community of the importance of appropriate management of water drainage for risk reduction. In addition, the research process promoted local understanding of the factors responsible for landslide risk and the importance of community-level monitoring the environment. The research led to better informed residents in regards to appropriate mitigation actions that can be taken by and within the community with guidance from academic institutions, and this knowledge exchange is being sustained by the Hillside Neighbourhood School.

Research phase 2: expansion of refined methodology to two additional communities

The initial action–research experience in Pinares de Oriente was expanded to two further communities in Medellín (Table 1; Medellín, Phase 2) with a similar exposure to landslide risk due to their location on steep slopes, high above the city in the north-east sector. The aim of this research was to apply a refined methodology to neighbourhoods with different histories and community characteristics, to explore the potential for transferring this approach to different socio-economic and political contexts within the same city (Smith *et al.* 2020b, 2021). The settlements chosen for this phase of the research included El Pacífico (in Comuna 8), a dense and consolidated neighbourhood, and Carpinelo 2 (in Comuna 1), a more recently settled and much less consolidated community (see Smith *et al.* 2020b for further details).

Engagement with these additional communities began through negotiations facilitated by local NGOs, which determined the process and agreements for the co-production of knowledge. Research in each area was then conducted following a similar structure to that in Pinares de Oriente, including: i) understanding local perceptions of risk through interviews with community and government stakeholders; ii) implementing participatory monitoring strategies, via selecting critical points with community researchers, who then regularly uploaded photos to WhatsApp groups; and iii) facilitating agreements between local community members, NGOs, and city authorities around pathways forward for risk reduction. Key refinements to the initial research methodology, based on lessons learned from the action–research in Pinares, included more extensive training on monitoring practices for community volunteers, along with fewer critical monitoring points (see Table 1), to increase engagement and volunteer retention (Smith *et al.* 2020b). In addition, administration of the WhatsApp groups, including a weekly top-up of mobile phone data, was conducted locally by a community leader and academic researcher based in Comuna 8, to encourage regular participation. These measures resulted in more consistent participation and therefore more systematic data collection (Smith *et al.* 2020b). Another key change to the action–research methodology was conducting regular workshops with community volunteers to jointly analyse the incoming data and ensure co-production of knowledge.

Although funding was not available for risk mitigation interventions within these two additional communities, possible future interventions were jointly identified by community members and the research team (Smith *et al.* 2021). Stakeholder mapping was also conducted to provide the communities with a departure point for future actions to be agreed. A key conclusion from research phases 1 and 2 was that landslide risk mitigation in these communities in the north-east sector of Medellín is intimately connected with drainage, as well as with pedestrian (and in parts limited vehicular) circulation pathways through the neighbourhoods (Smith *et al.* 2021). The research therefore highlighted that landslide risk management at the neighbourhood level in these areas is intrinsically linked with the urban infrastructure, demonstrating the scope for the co-production of risk mitigation infrastructure in the built environment.

Research phase 3: linking community-based water and risk management with institutional plans and programmes

The initial research phases in Medellín highlighted the importance of integrated risk and water management to reduce vulnerability in the informal communities of the north-east sector of the city. Our ongoing research in Medellin is therefore focusing on the co-production and testing of appropriate infrastructure solutions that engage with national and local investment programmes for neighbourhood improvement. The research is exploring the development and implementation of co-produced water-related and risk management solutions within wider spatial planning and housing-related policies in three new case study neighbourhoods: El Faro (Comuna 8), Bello Oriente, and San José la Cima 2 (the latter both in Comuna 3).

The research is providing a framework for co-created water management infrastructure, identifying responsibilities across different stakeholders: that is, at the family/household level, within groups of neighbouring houses, with the community network at the neighbourhood level, and institutional responsibility for public infrastructure. This is being carried out through a series of workshops and focus groups within the framework of a ‘Laboratory of appropriate technologies for the strengthening of community autonomy in water and risk’, integrating a disciplinary dialogue between environmental, technical, and social knowledge within a comprehensive approach linking water infrastructure and risk management with enhancing community agency and action. Preliminary diagnostic activities have identified that integrating climate change adaptation within a long-term planning vision is a strategic priority both within community organisation agendas and within institutional policies and programmes. This synergy has opened opportunities for establishing a 'dialogue of knowledges' between community members and local government, with the potential to shift the balance of power in risk management in informal areas of Medellín towards increased community agency, through co-producing innovative and sustainable solutions to water-related risk management.

3.2. Understanding and mitigating climate-change-related risks in Puebla, Mexico

Rapid urbanisation around the city of Puebla has created a sprawling metropolitan area, which is increasingly encroaching on neighbouring communities, affecting both the social and the environmental fabric. Increased demand for water for residential and industrial use, combined with deforestation and land-use change which have reduced aquifer recharge, threaten the viability of community wells. In addition, surface water flows such as rivers and streams are highly polluted due to poorly regulated discharge from urban areas and insufficient water treatment from industry (e.g., Casiano Flores & Bressers 2015). In parallel, climate change has been accompanied by a significant reduction in overall precipitation in central Mexico, driving increasing water scarcity, while very heavy rainfall events have increased (Groisman *et al*. 2005), promoting flash flooding.

Research phase 1: identifying climate-change-related challenges and possible 'smart city' adaptation strategies through an interactive dialogue between stakeholders

Our initial research in the municipality of San Andrés Cholula focused on understanding the impacts of climate change in low-income, urban–rural edge communities affected by the expanding urban fabric. The city of Puebla is one of the fastest growing municipalities in Mexico. Between 1980 and 2010, San Andrés Cholula experienced a greater rate of urban growth (4.6 per cent) than the Puebla city centre (2.1 per cent) (OECD 2013), effected through a large-scale urban development plan. Through implementing an interactive dialogue between community members, public sector organisations, NGOs and other stakeholders, the research aimed to identify climate-change-related challenges at the local level and provide a framework for the agreement of possible 'smart' solutions based on the experiences of local people. This approach contrasts with a recent unsuccessful top-down attempt to implement 'smart city' technologies in one of the municipality's neighbourhoods, Santa María Tonantzintla, which discounted the experiences and knowledge of the targeted urban communities and was rejected by residents (Wattenbarger 2018).

Over twelve months, the research team engaged in qualitative data collection through focus groups, workshops, site visits, and semi-structured interviews with government authorities, local urban and rural communities, civil organisations, and academic actors (Table 1). To understand local stakeholder perceptions around climate-change-related risks, a series of focus groups were held with local community members, including representatives from six districts in the municipality—Santa María Tonantzintla, San Francisco Acatepec, Cabecera de San Andrés Cholula, San Bernardino Tlaxcalancingo, San Antonio Cacalotepec, and San Rafael Comac—who were all members of a grassroots movement named 'Cholultecas United in Resistance' (*Cholultecas Unidos en Resistencia*), created in reaction to recent urban development decisions that failed to consult and consider local needs. Focus groups were also conducted with actors from the public, private, and third sectors, including environment and urban planning researchers, local public officials, entrepreneurs, civil organisations, and NGOs such as Oxfam, UNDP (United Nations Development Programme), and *Ayuda en Acción* (*Help through Action*, an NGO has worked across Mexico over the past twenty years helping to defend the rights and dignity of vulnerable communities). During these participatory processes, discussions took place around the history of the community, and the challenges and vulnerabilities in terms of climate-change-related risks. An important challenge perceived by local communities was in relation to the *2018 San Andrés Cholula Urban Development Plan*, due to the impact of urban expansion in reducing agricultural land and displacing local communities due to higher taxation and a fragmented urban structure.

Overall, the research identified three overarching challenges experienced by the local communities:

- *Water Management*: The recent urbanisation and population growth are affecting the recharge of the aquifer from which most people extract water from wells for household use. In parallel, new housing developments are increasing the demand for water. Water security risks therefore exist due to aquifer overexploitation, as well as changes in agricultural practices and inadequate waste management from housing and industry, which are observed to be polluting the soil and the water. In addition, participants identified that urban development and 'progress' linked to paving and construction have increased the risks of flooding.
- *Urban Expansion*: Rapid urbanisation has occurred in the absence of territorial planning, driving the loss of agricultural land, traditional housing, a loss of identity, a lack of neighbourhood cohesion, a lack of inclusion of green areas, and deforestation.
- *Pollution*: Poor waste management and the use of chemical fertilisers have led to the contamination of soil and water; rubbish in the streets is contributing to flooding by blocking drains; and air pollution is affecting residents, connected

to congestion and poor-quality public transport. In particular, communities linked the use of chemical fertilisers with education and behavioural issues.

Although government-enforced regulation was viewed as important, the need for knowledge acquisition around risks was strongly expressed by local communities. Specifically, communities wanted greater knowledge of the impact on the natural environment of adaptation strategies they may put in place to tackle climate-change-related risks, and raised the need to collect and share information within their community and with public sector organisations. Education, in terms of receiving as well as collecting data, was therefore viewed as a priority, to inform communities' everyday decision-making and practice in relation to the environment. Moreover, residents valued better understanding of the negative influence that their actions may have on the natural environment and welcomed knowledge of potential strategies, such as recycling, managing food waste, and sustainable crops, to mitigate these negative impacts. As a transition from traditional agricultural land use towards urban land use is occurring in this area, more sustainable agricultural practices were identified as a priority, due to a concern that the development of crops could worsen climate change impacts and perhaps increase flooding. A particular threat highlighted for this area was the removal of trees without considering soil conditions, the potential for absorbing rainwater, and buffering the negative effects of chemicals used on crops. Sustainable waste management was also identified as key in terms of knowledge development.

Another challenge identified by the communities was related to coping with the impacts of high-intensity rainfall events before, during, and after they occur. For example, receiving timely warnings of heavy rainfall was viewed as critical to mitigate damage from flooding. Although most members of these urban communities have Wi-Fi access and use data on their mobile phones, a specific communication tool is not in place to provide warnings and trigger specific actions before and during a heavy rainfall event. Opportunities for action in these areas therefore relate to education and knowledge exchange programmes, infrastructure systems for water collection and drainage, water filters, and community-informed technological solutions.

Through understanding local perceptions around risks, and the actions being taken at the community and institutional levels, the research sought to create opportunities for knowledge exchange between communities, and technical, professional, and government actors, in order to agree and co-create actions focused on tackling climate-change-related risks. The research explored short-, medium-, and long-term impacts of the identified risks at the household level, in the public space and in the productive (agricultural) space, within an integrated framework considering different geographical scales, which was rooted in jointly determining the different levels of responsibility when developing solutions. The findings of the research in relation to climate-change-related impacts perceived at the local level were presented and validated through three multi-stakeholder workshops where possible actions for reducing these risks were identified and agreed. In addition, as the *Urban Development Plan* was perceived as a key factor increasing risk, the research team helped to engage communities in the consultation process for the Plan, promoting a platform for negotiation.

The research identified a range of challenges in relation to climate change within this complex area interlocking both urban and rural conditions. The project provided a framework for knowledge development and exchange, engaging and promoting community-level action. At the same time, the research generated a platform for dialogue and reflection between local residents and authorities, mediated by academic representatives, on the basis of which agreements were reached to incorporate community needs into the *Urban Development and Environmental Management Plans*. The knowledge developed and actions agreed at the neighbourhood level were upscaled by small resident groups leading projects to recover old water channels and ditches, plant trees, and transform their own houses to contribute to rainwater capture. In collaboration with institutions, these efforts could be scaled up to achieve wider impact across the region.

Research phase 2: co-creating water security in the Upper Atoyac River basin

Communities in San Andrés Cholula perceive that urban development policies and programmes have been an important driver of water pollution, water scarcity, and inadequate water management. Through generating trust and commitment from local organisations, government institutions, and communities, our initial research identified a knowledge gap around actions and policies that could, in combination with technological solutions promoting knowledge exchange and communication, reduce the negative impacts of climate-change-related risks. This research demonstrated that 'smart' decision-making should not only be rooted in public participation but also in informed public action with a long-term vision.

Importantly, the initial research highlighted that water management and governance at a range of geographic scales—from the household level, to the neighbourhood and municipality levels—is key to addressing climate-change-related risks in the area, motivating a broader range of stakeholder consultations in urban and rural communities over the wider river basin relevant to the city of Puebla, the Upper Atoyac River basin (UARB). Qualitative and quantitative data collection has contributed to developing water security indicators incorporating the aspects of scarcity, quality, and vulnerability. In addition, hydrological modelling is allowing us to project the future trajectory of these indicators under regional climate change scenarios, with the aim of identifying critical areas of water scarcity, and co-developing and testing strategies for improved long-term water security in the UARB.

4. Discussion

4.1. Importance of local perceptions of climate-change-related risks to inform risk management strategies

Despite the growth and mainstreaming of participative approaches to risk management (Maskrey 2011), these have had limited impact at the global scale. This has been attributed to a lack of understanding of underlying drivers of risk, such as uncontrolled urbanisation, land-use change, or the growth of informal settlements. It is therefore essential to review, conceptualise, and implement action around the social dimension of risk management. In addition, many risk reduction initiatives implemented at the local scale by NGOs and other extra-community actors lack local ownership and tend to end when the programme ends, undermining sustainability (Maskrey 2011). In order to achieve long-term action and change, it is essential to understand the willingness and capability of stakeholders to participate in locally based initiatives, as well as the geographical scale of actions that are needed, and the responsibilities (that is, powers) of different stakeholders within strategies to reduce risk.

In addition, due to considerable uncertainty around the regional impacts of climate change, the lay knowledge of people who experience local impacts is of crucial importance for guiding risk management. Moreover, household coping strategies are an essential component of risk management, but developing the full potential of these strategies requires community empowerment and, often, technical assistance. Our action–research approach engaging with local communities in Medellín and Puebla has helped to understand the complexity of the risks associated with poor water management, which results in increased vulnerability to climate-change-related risks (for example, exposure to landslides, flooding, and/or water scarcity, depending on the setting). In addition, the research demonstrated that urban communities are able to identify their own vulnerabilities in the context of climate change impacts, and are willing and capable of co-producing risk management solutions to build local resilience to the impacts of climate change, when working in collaboration with local organisations and academia. Furthermore, these experiences have shown that community engagement should occur at all stages of a project, from planning to execution and maintenance, allowing local people to take ownership of the proposed actions.

In particular, our research in informal and low-income areas at the urban–rural edge in cities of Latin America has shown that more integrated participation of local people in risk and water management in a territory leads to 1) a more accurate understanding of the impacts of climate change and development decisions on daily lives and livelihoods, and 2) data collection at finer spatial and temporal scales than is often possible for the institutions traditionally responsible for risk management. In the context of increasing the adaptive capacity of vulnerable urban communities to climate-change-related risks, these experiences highlight the need to first understand risks as experienced by people living in a given setting, and to explore means to connect government actions with community knowledge, to enable the identification and agreement of sustainable solutions, and potential upscaling of mitigation and adaptation strategies.

4.2. Establishing a 'dialogue of knowledges' to identify technically appropriate and culturally accepted risk management strategies

In order to achieve a greater degree of risk reduction, it is important to expand actions from the local scale to address structural issues on a greater scale, which are commonly beyond the reach of local actors (Maskrey 1984, 2011). It is therefore essential to explore the scope for 'co-production' at different geographical scales and across different organisations, to understand priorities, responsibilities, and roles. Our research has explored these alternative forms of engagement between local communities and government institutions for risk management, beyond merely consultative forms of public participation. Co-produced solutions piloted through our collaborative research demonstrate the need for stronger involvement from both community and state institutions in the development of more informed and integrated risk management strategies, across different levels of responsibility (for example, individuals, communities, and municipal governments) and the corresponding geographical scales (that is, individual dwellings, groups of dwellings, neighbourhoods, municipalities, and river basins). Academia and local NGOs can play a significant role in facilitating these interactions and establishing channels that allow opportunities for negotiation and agreement, particularly in engaging a wider range of stakeholders in risk management and risk governance.

Our research in both Medellín and Puebla demonstrates that increasing the adaptive capacity of informal and low-income urban communities in the face of climate change entails empowering them to use their knowledge and resources to understand and monitor risk. Establishing a means for dialogue and knowledge exchange can then support effective interactions between stakeholders: for example, communities and public sector authorities responsible for decision-making and for the development and implementation of risk management programmes. Our experiences in Medellín and Puebla showed that integrated risk management strategies that place local knowledge on a level platform with other forms of knowledge can increase community agency by empowering local people to participate in decision-making, allowing a shift in the power dynamics at the local and neighbourhood scales. This shift can enable both technically appropriate and culturally accepted, and therefore more sustainable, solutions to be reached, as well as opportunities for upscaling actions, opening a pathway beyond simply building resilience at the local level, towards adaptive transformation in the framework of Pelling (2011).

4.3. The role of 'smart' technologies in building resilience and adaptive capacity

Our experiences in Medellín and Puebla motivate reflections on the vulnerability of low-income and informal urban communities, climate change adaptation, and the role of 'smart' technology in risk management. Our research demonstrates that connecting these concepts through a qualitative action–research programme can bridge interdisciplinary divides and provide novel insights for adapting to climate-change-related risks. The research in Medellín demonstrated that 'smart' technology can serve as a channel for communication that facilitates a regular, continuous dialogue between stakeholders (in this case, communities and technical experts), which is especially effective when community members are empowered to act as equal stakeholders participating in data analysis and decision-making. The research in Puebla showed that communities need easily accessible information and communication tools to enable them to share observations of their environment and identify appropriate adaptation actions. Furthermore, governments require detailed knowledge of local impacts to guide policies and programmes that truly meet community needs. Our research therefore motivates greater interaction between communities and public sector organisations in the creation and implementation of 'smart' technologies intended to facilitate risk management and sustainable urban development. Examples of valuable technological solutions are those that provide two-way (communities and authorities) access to data on local resources, risks, and adaptation actions, through hosting community managed maps, discussion forums, infographics, and interactive visualisation tools.

Our research shows that local citizens are able to monitor their environment at a finer resolution than the authorities responsible for risk management. However, these actors do not easily influence decision-making. Our action–research has demonstrated the value of easily accessible information and communication tools able to link top-down, 'traditional' forms of governance with bottom-up initiatives, facilitating knowledge exchange around potential climate change and urban development impacts and strategies. 'Smart' technological approaches that facilitate this dialogue hold the potential to harness local knowledge, resources, and participation, as well as technical and professional knowledge that tends to be compartmentalised within privileged sectors of society. On the basis of our experiences in Medellín and Puebla, we argue that co-producing and co-managing appropriate ‘smart’ technologies therefore represents an important step to catalysing sustainable knowledge exchange between stakeholders, and empowering communities through shared responsibility to adapt to climate-change-related (and other) risks.

5. Concluding remarks

Adaptation solutions should be relevant and tailored to local climate change impacts, which in urban environments are intimately connected to development policies and strategies. Our research has highlighted that communities are able to identify solutions if horizontal flows of knowledge are enabled and relationships of trust are established. If supported by suitable technologies, the knowledge generated by action–research approaches, such as those in Medellín and Puebla described in this paper, can spread beyond the local level and beyond the timescale of these projects, allowing continuity in data collection and dialogue. Nevertheless, solutions may be difficult to identify at the necessary scale without financial support and policy enforcement. Context-specific and appropriate technologies therefore need to be identified, and the participation of local residents as well as local (and national, where necessary) governments is needed to co-produce and deliver appropriate adaptation and mitigation strategies. This is where we believe that ‘smart’ technology can serve as the connection bringing communities, their experiences, needs, and knowledge, together with the required political influence, financial support, and scaled policy development. We therefore advocate for the development and implementation of strategies that use ‘smart’ technology, when these are co-produced and co-managed between diverse stakeholders, to help establish trust and continuity of data collection, dialogue, and risk management beyond political cycles.

With respect to the challenges facing low-income and self-built communities in the Global South exposed to climate-change-related risks, our work has contributed to strengthening organisational and technical capacities at the local level, developing methodologies with the potential to increase community autonomy and question traditional forms of governance. Within this perspective, our work has promoted the decentralisation of the management of ‘common goods’, recognising stakeholder organisational capacities and interests, as well as conflicts, in risk governance. This approach encourages social cohesion and communal appropriation of the developed solutions and infrastructure, promoting the expansion of the margins of local democracy. Therefore, co-produced actions to tackle climate-change-related risks, could be linked with a higher level of autonomy and agency at the community level when making decisions around urban and resources management. Vulnerable communities can be empowered by interactions and dialogue between different stakeholders. Our research has provided evidence that informal urban communities are able to monitor their territory and implement and use ‘smart’ technology to mitigate climate change risks if (1) these technologies allow bottom-up participatory adaptation measures, and (2) training and support from a multidisciplinary team including representatives from public sector organisations as well as academic researchers and technical experts is provided. Future research should explore the potential for these strategies and techniques to be rolled out at a wider scale with community-based researchers, leveraging training and communication programmes, establishing mechanisms replicable to different cities, and creating society-wide change by rebalancing community/institutional power relations—using co-produced ‘smart’ technology that incorporates community knowledge and experience, and simultaneously helps to create and influence climate-change-related local and national policies.

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Climate change and strategic low-carbon planning in African cities after COVID-19: inclusiveness or chaos?

Xavier Lemaire

Abstract: Cities in sub-Saharan African countries are feeling the impact of climate change with an increase in climate refugees and they have to deal with more intense flooding, land degradation and erosion, droughts, and heatwaves affecting in particular the poor living in informal settlements. Strategies on how to adapt and move to more resilient cities are being designed. But the question is how this transition can be done while municipalities in sub-Saharan Africa are facing difficulties coping with demographic growth, budget scarcity, and poor governance. Most local authorities in sub-Saharan Africa have consistently failed to address the fundamental basic needs of communities, even before the current acute environmental crisis. This paper analyses the persistent urban planning bias preventing transition to sustainability, emerging alternative strategic options promoting resilience and inclusivity while moving toward low-carbon cities, and how the discourse on post-COVID cities is relevant to the context of urban Africa.

Keywords: Climate change impact, extreme heat, flood, informal settlements, strategic urban planning, sub-Saharan Africa, low-carbon transition, neoliberalism, social status, car-free city, climate adaptation, inclusiveness.

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Introduction

This article reflects on the impact of climate breakdown on African cities. The relations between social status consumption and the transition to low-carbon cities and societies need to be explored. Inequalities in sub-Saharan African cities are not only shocking but could block any form of sustainability transition. The desire for over-consumption and the high-carbon way of life by the elite and the growing upper-middle class, combined with a top-down process of spatial segregation, could lead to the persistent marginalisation of the poor, and, in a context of weak governance and scarcity of resources, render any climate adaptation impossible.[1] But the emerging practices of some African cities could challenge the social imaginary of stakeholders intervening in the field of urban planning by proposing concrete paths of mitigation and adaptation.

Otherwise, if urban planning continues to be left to practices disconnected from the daily lives of the poor and to support the marketisation of cities, climate change is likely to accelerate the dislocation of cities as urban space (that is, space of urbanity/civilisation). This process of fragmentation/privatisation—well engaged all around the world—tends to be exacerbated in sub-Saharan African countries; this is due to a general lack of capacity of intervention from local authorities and outdated and inadequate notions of what are contemporary forms of urbanism assimilated to modernisation. The absence of reflexivity amongst planning communities leads to the reproduction of the same errors; a paradigm shift based on the inclusion of all stakeholders in planning processes is needed for the complexity of cities to become manageable and avoid systemic failures (Coaffe & Lee 2016: 73–247).

The literature on African urban planning has focused until now on the multiple barriers to sustainable transition, notably the weak governance capacity of African municipalities and the disconnection between urban development policies and local realities. There has been only limited literature on concrete paths for a sustainable transition in cities of the Global South, even at an international level; the call for citizen participation in urban planning and for an 'epistemic community' is not recent but until now has not so often been put into practice (Pieterse 2006, Lemaire & Kerr 2014). But the acceleration of climate change effects and environmental degradation is putting cities even more at an existential crossroads which seems to require radical changes in mindset and urban planning practices (Cobbinah 2021).

African civil servants and elected members do face daily difficulties in administering cities that are quite different from their European counterparts. This paper aims to

[1] Equity, community participation, and integration of diversity appear to be prerequisites for resilience (Bahadur *et al.* 2013).

understand what low-carbon strategies could be grounded in the reality of an African city. It is based on a literature review on urban planning in Africa, notably critical books, reports, and papers from African urban planners and researchers, focusing on what needs to be changed to make African cities resilient to climate change and how ongoing discussions of post-COVID cities could realistically apply to African cities.[2] After characterising African cities and the impact of the climate crisis in urban sub-Saharan Africa, this paper reviews alternative models for low-carbon and resilient cities that are attracting renewed interest with the advent of COVID-19. Are these models adapted to the context of urban Africa? If not, how could they be adapted? By mobilising what resources? Knowing that African countries generate only a small amount of greenhouse gas emissions, are mitigation measures useful or should authorities focus on adaptation measures? In brief, what could low-carbon transition mean in the context of sub-Saharan African cities?

I. African cities and climate breakdown

Sub-Saharan African cities as an archetype of the urban crisis?

In the discourse produced by international organisations, non-governmental organisations (NGOs), media, consultants, and researchers, African cities may be presented as places of chaos, uncontrolled growth, and poor governance. A dystopian future would lead to the perpetuation of bleak living conditions for their poorest inhabitants (Davis 2006). Climate destabilisation would further condemn them to an endless spiral of depression and violence, as African cities would have no means to adapt (Planitz 2019).

Cities in sub-Saharan Africa are diverse and the use of a generic term like 'African cities' remains debatable (Myers 2011: 2–7).[3] The former view of African cities as hopeless places of chaos can be tainted with racism and neocolonialism. The term

[2] This article is based on a literature review of emerging innovative urban planning practices; it also builds on discrete observations in several municipalities in sub-Saharan Africa during recent research–action projects co-led by the author on low-carbon society transitions; notably an EPSRC–DfID project on Supporting African Municipalities in Sustainable Energy Transition (2013–17) in South Africa, Ghana, and Uganda; this four-year policy-oriented project about integrating energy in municipal action involved informal interactions with African officials from six African municipalities during a number of workshops and capacity building events.

[3] This article aims to contrast the situation of African cities with their European counterparts. African urbanisation is different from that of other regions of the world due to the history and governance of the region (Dodman *et al.* 2017).

'African cities' is often used de facto to describe urban places that do not comply with the ideal of a city as incarnated by Western cities; they are places of 'failed modernity' defined by a lack of, more than the result of, any autopoiesis/endogenous creation. On the contrary, grass-roots actors emphasise the capacity of resilience and creativity of the poor, which could lead to a new imaginary (Harrison 2006). For a 'neutral' observer which we aim to be, the accumulation of challenges faced by African cities does look daunting. Active adaptation strategies, aiming at promoting transformational city models and going beyond coping mechanisms, are needed (Bulkeley 2013: 142–89).

If the archetype of a doomed megapolis like Lagos conceals diverse urban forms, small and medium-sized African cities, where around half of urban Africans live, do not appear to be better off than the large conurbations (Gandy 2006, Dodman *et al.* 2017, Satterthwaite 2017). Most African cities tend to face similar issues when it comes to basic services/functionalities—issues unknown in OECD countries, or less acute: a shortage of electricity supply, lack of appropriate sanitation network, explosive accumulation of solid waste with a limited capacity for treatment, reduced mobility due to permanent and inextricable traffic congestion, a high level of air pollution, etc. Rapid human growth and poor state capacity of intervention are common in all African countries, and, if patterns of urbanisation can vary (AfDB *et al.* 2016: 155–8), slums are preponderant and are particularly vulnerable to climate change (Williams *et al.* 2019). In 2015, 59 per cent of the urban population in sub-Saharan Africa was living in informal settlements against 28 per cent in Asia and the Pacific (UN-Habitat 2016: 8). African cities also have the commonality of most of them being located in very-low-income countries [4,5,6] and the African population is very young compared to other continents, which makes inhabitants even more vulnerable.[7]

Another common feature of African cities is the colonial heritage present in the physical urban space of African city centres and in the persistent way that urban planners function with variations according to the former colonisers' country (Watson & Odendaal 2012, Silva 2015). Inherited urban planning practices in Africa are still based on a top-down approach where planners try to control and allocate space

[4] Human growth can reach up to 6 per cent per year. https://data.worldbank.org/indicator/SP.URB.GROW?locations=ZG

[5] The majority of failed states, critically weak states, and weak states are located in sub-Saharan Africa (Rice & Patrick, 2008).

[6] Some cities in Asian and Latin American countries face the same difficulties as African countries, linked to limited capacity of intervention due to limited financial resources and poor governance. But 36 out of the 47 least developed countries in the world can be found in sub-Saharan Africa. https://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/DAC_List_ODA_Recipients2018to2020_flows_En.pdf

[7] In 2015, children under 15 accounted for 41 per cent of the African population against 26 per cent in Latin America and 24 per cent in Asia (Dodman *et al.* 2017, quoting UN-DESA 2015).

according to preconceived ideas transferred from the Global North of what is a good city for the dominant class, leaving aside the poor (Coquery-Vidrovitch 1991, Watson 2009). Segregation was and remains at the core of urban planning in African cities, even if urban dynamics always evade social control and fixed territorialities (Polomack 2010); the spatial separation between white colonisers and indigenous communities has mutated into:

1. social segregation according to income and location in the city along with ethnicity, a marker of social status in the post-colonial city where urban dwellers continue to be rural subjects ruled by traditional leaders instead of citizens (Beall 2006);
2. the separation between the formal city serving external interests—planned and benefiting from the minimal attention of decision-makers and the informal city—uncontrolled by urban planners and often seen as a chaotic space to be organised, a place filled with undesirable constructions producing (in the view of officials) a poor image of the city.

The idea of segregation as a fundamental driver of urban planning in Africa comes on top of:

3. the radical urban planning philosophy inspired by Le Corbusier (1929, 1964, 1973), notably separating urban space into urban functions between work, leisure, and residential, and the idea of a modern city based on a strict grid pattern (as opposed to the informal unplanned city, which is to be eradicated);
4. the fragmentation of public action between different administrations with little horizontal communication—aka the silo effect—which translates into uncoordinated territorial actions.

Climate adaptation would imply critical reflexivity on maladaptive practices and integrative policies to reverse these four centrifugal tendencies, This paper will now address these points in more detail.

Impact of climate destabilisation in urban Africa

Climate destabilisation is, along with other types of environmental degradation, impacting cities in Africa in multiple ways. Africa is considered to be the most vulnerable continent to climate events due to the vulnerability of agricultural systems and its low-level capacity for adaptation linked to its poverty (Niang *et al.* 2014). The repetition of extreme weather events, their intensity and their severity create a new situation where urban planning practices need to build resilience around uncertainty; a permanent succession of disruptive impacts could otherwise have a systemic and cumulative debilitating effect on the functionality of a city.

One noticeable impact of climate destabilisation is the sudden increase in internal and inter-regional migration linked to the loss or degradation of livelihoods in rural areas. The number of persons displaced by disasters in Africa was been estimated to have been around 21 million between 2008 and 2019 (IDMC 2019); however, migration always results from a complex of causation issues, making estimates of the number of climate or environmental refugees highly debatable (Parnell & Walawege 2014).[8] Refugees can resettle in camps, informal settlements, or squats near or within African cities.[9] [10]

African cities seem to have a high capacity for the integration of newcomers. The impact of global migration flux in African countries might generate less tension than in Europe;[11] contrary to common belief, refugees tend to integrate quickly and, far from being passive victims, can consolidate transnational trade networks (Campbell 2006: 125–47). Nevertheless, a sudden influx of migrants can put pressure on weak infrastructure and the job market, potentially generating xenophobic tension or leading to migrant communities being neglected (Asibey *et al.* 2021).

Major cities in Africa are located within coastal areas or near large rivers;[12] they are already feeling the effects of land erosion, which reduces the space available for inhabitants and is highly disruptive of their social activities.[13] The recurrence of flooding is a serious issue as it means a repeated loss of income and belongings, if not loss of lives (Douglas *et al.* 2008, Gough *et al.* 2019).

In hot and humid cities located in the subtropics,[14] the increase in temperature exposes their inhabitants to heat stress aggravated by air pollution. Increased heat impacts the well-being of people who cannot afford air-conditioning (the vast majority); this is especially true for those living in informal settlements in rugged iron

[8] There is no established definition of climate refugees; they are persons being displaced either by the direct consequences of climate events, like droughts or floods, or indirectly when climate events have triggered armed conflicts (Apap 2019).

[9] Contrary to the imaginary belief socially constructed by an ‘invasion’ of Europe, the flux of migrants from Africa towards Europe is marginal compared to the inter-African flux (IDMC 2019).

[10] It is estimated that 60 per cent of refugees in the world live in urban areas (UNCHR 2016).

[11] Even with all the socio-economic problems African countries are facing, African politicians may tend to put less pressure on instrumentalising (related to the number of migrants in Africa compared to Europe) the question of migration than their Western counterparts.

[12] Access to the sea or a watercourse, which was an asset for cities allowing communication and access to resources like water or fisheries, could now be a handicap due to climate change.

[13] Saint-Louis of Senegal illustrates well the impact of erosion and modification of the regime of the Senegal River; fishermen have to move to Mauritania to pursue their activities (personal interview, January 2020).

[14] Since thermal comfort is dependent on temperature and humidity, cities under the tropic may be as vulnerable—even if the temperature remains around 30°C—as cities in arid regions.

shacks where living conditions are truly unbearable (Gough *et al.* 2019, Pasquini *et al.* 2020).[15]

An increase in the spread of tropical infectious diseases is another possible consequence of climate change (Wu *et al.* 2016). The density of population and poor living conditions make tropical diseases more difficult to control in urban areas. The history of pandemics and tropical diseases shows that they have been instrumental in triggering changes in urban planning (Njoh 2012: 19–54). Environmental health could be a major field of intervention for African municipalities without requiring costly modern European solutions, by reconnecting urban planning with interdisciplinary health initiatives (Njoh 2012). Better sanitation, waste management, access to clean water, quality housing, and economic security for the breadwinner contribute as much as health infrastructure to preserving the health of a population.

Cities are dependent on their environment as they import natural resources. Repetitive droughts can reduce water supply and lead to restrictions in regions pumping too much water to satisfy the competitive needs of all stakeholders, notably farmers. Acute water scarcity is a reality in Southern Africa and can lead to severe water restrictions.[16] Another consequence of climate change is the increase in food prices, which negatively impacts the poor, who devote the largest share of their budget to buying food.

High-carbon versus low-carbon paths?

The impact of climate change on African cities is and will be more severe than in European cities because of the already-existing conditions linked to subtropical and arid areas, the multiple difficulties African municipalities face in providing basic services, and their limited financial capacity, which prevents them from opting for easy technological fixes instead of costly ones. This latest limitation could paradoxically prove to be, in the long term, an incentive to implement more resilient sustainable

[15] Temperatures inside shacks can reach 3 to 8°C higher than outdoors; extreme heat has a significant impact on the life of slum inhabitants. These people prefer to sleep outside, which renders them vulnerable to mosquitoes and theft; their productivity at work is lower (Gough *et al.* 2019).

[16] After three dry years, Cape Town had to impose a quota of 50 l/inhabitant/day during the drought of 2018; the municipality contingency plans and aggressive communication campaigns, which mobilised everyone, eventually helped to push back Day Zero when the municipal supply of water would have been shut off (local media & personal interview, January 2018). The water crisis could be blamed on climate change which increased uncertainties but also delayed infrastructure investment (Muller 2017). It may have led to a deepening of inequalities in water access with a reinforcement of the logics of commercialisation of water as the municipality withdrew the universal provision of free basic water and changed its tariff structure (Millington & Scheba 2021); there has been also a multiplication of off-grid solutions by the wealthy (Simpson *et al.* 2020).

solutions, as technological fixes can offer only temporary or partial solutions while sometimes being carbon-intensive and environmentally destructive.

Unlike their European or North American counterparts, African cities cannot opt for costly high-tech or capital-intensive solutions to protect their assets and inhabitants. They cannot build many extended seawalls and costly flood barriers to protect them from coastal erosion and rising sea-levels. Heat cannot be fought systematically with air-conditioning, which in Africa remains the privilege of upper-class houses, commercial buildings, and office complexes; costly water pipelines or desalinisation treatment plants are an option only for the wealthiest municipalities.[17] Water scarcity could mean their demise.

In an African context, collective or individual high-carbon technologies with high capital or running costs tend to be out of reach of the poor and could reinforce their exclusion from the city, while low-carbon strategies could be more inclusive. If the capacity of African municipalities to intervene through the construction of major infrastructure seems limited, small collective actions may make a difference and reduce the impact of extreme events. Low-carbon solutions could go with lower capital costs and higher local job creation while being easier to maintain when built on local knowledge.[18]

What could the post-COVID city be in an African context?

COVID-19 is widely considered to be an accelerator of change which has had a significant impact on cities; some cities have reacted better than others due to their governance capacity and more diverse and resilient economic systems (Sharifi & Khavarian-Garmsir 2020, Simon *et al.* 2021). In the current debates about a post-COVID world, some well-known low-carbon and cost-effective urban design forms have been identified, which could not only contribute to adapting to climate change but also help mitigation while contributing to a reduction in social inequalities. The post-COVID city could be a sustainable city, a vernacular city, a healthy city, a bio-city, a post-carbon city, a good city, a liveable city, a resilient city, an inclusive city … to take a few of the denominations from past research in urban studies (Ratho & Lourdes John 2020).

[17] Cape Town, facing the severe water restrictions of 2018, has opted for temporary desalinisation plants, which will be replaced by large-scale permanent ones.
https://www.capetownetc.com/news/city-decommissions-standfontein-desalination-plant/

[18] There are exceptions: the capital costs of individual renewable energy technologies like solar home systems are higher than conventional sources but cheaper to run on a life-cycle basis.

Recurrent topics in the literature on what a city's future could be can be found around:

- low-carbon buildings or the vernacular city,
- soft mobility and the car-free city,
- the importance of green spaces or the bio-city,
- the recognition of urbanity as the creation of commons.

Unlocking sustainable cities implies action on those four points (Chatterton 2019). In the specific context of the Global South, the last point is particularly important as African cities are, for the most part, informally co-built by their inhabitants, and moving towards a more resilient city either against COVID-19 or climate change cannot be achieved without the recognition of this informality.[19]

II. Elements of low-carbon socio-technical strategies

Low-carbon—the vernacular city

The rise of office blocks made of concrete, steel, and glass—symbols of modernity prevalent in the business areas of African capitals—goes along with the construction of commercial centres, luxury residential complexes, and miles and miles of suburban upper/middle-class houses (often in gated communities), representing a characteristic form of architecture imported from Western cities, which tends to valorise individual consumers/nuclear families. Sometimes architectural gestures relying on the recycling of local signs/shapes are mobilised for major buildings, which will act as a symbol of Africanity (Bekker & Therborn 2012).

These modern (small or large) buildings can be costly to maintain; they tend to be energy-intensive and closed to their immediate environment, relying on air-conditioning, the use of artificial lights, lifts for high-rise buildings, and telecommunications of all sorts. Rising temperatures and an appeal to air-conditioning can put a strain on an already-overloaded electricity network that has, in most African countries, difficulties coping with increasing demand.[20]

[19] The fragility of African cities underlined at the beginning of the COVID-19 pandemic has been used as a call for change in Africa as in the rest of the world (UN-Habitat 2020).

[20] Air-conditioning and electric fans represent 10 per cent of all global electricity consumption today (IEA 2018). Incidentally, the multiplication of substandard air-con not only increases energy bills but also generates supplementary noise while extracting heat to eject it outside.

However, low-carbon solutions exist for modern buildings both in the choice of materials and in the choice of design: concrete or steel which are carbon-intensive could be replaced by equivalent materials generating less carbon emissions (but currently costly to produce) (Bataille 2019) or more likely by cheaper vernacular materials like timber, bamboo, laterite, or clay[21] (Agyekum *et al.* 2020). Passive housing[22] in tropical areas may be still in its infancy, but the design of well-ventilated and shaded open space has existed for centuries without requiring any substantial energy input.

Residential housing could potentially evolve towards more vernacular forms with an architecture adapted to local climate conditions rejecting air-conditioning as a norm by relying on natural climate;[23] using local materials could reduce the carbon intensity of buildings, create jobs, and help to mitigate climate change,[24] but also contribute to adaptation to climate change as local materials can generate better insulation. However, this would imply an adaptation of building regulations (Heisel & Kifle 2016: 166–76). Decentralised renewable energies like thermal solar[25] may help to heat/cool buildings and provide hot water without imposing on the electricity network. Solar photovoltaic electricity is now cheap enough to power houses and contribute to a significant part of the electricity needs of commercial buildings. The recycling of water and collection of rainwater in closed tanks could help to reduce flooding and the consumption of clean water.

The poor who rely on self-construction of their homes on small parcels need access to materials providing better insulation—for a marginal cost, programmes providing roof insulation and wall insulation have been proven to make a significant difference in terms of thermal comfort.[26] Providing adequate materials or basic structures can help them to consolidate/build their homes and give them better resistance to extreme events (Blair 2012). The adoption of minimal building regulations targeting informal settlements may lead to their observance, more than a set of complex regulations,

[21] https://inhabitat.com/11-green-building-materials-that-are-way-better-than-concrete/

[22] Passive houses are houses with a low carbon footprint; they combine high energy efficiency standards and a high level of insulation, and harness natural energy sources, which lead to very low need for conventional active source of energy for heating and cooling: passive sources are the Sun, or the heat coming from human bodies or produced by household appliances.

[23] Unfortunately, even if vernacular architecture is generating a growing interest worldwide, studies on the African continent remain rare (Nguyen *et al.* 2019).

[24] The carbon impact of African cities may still be low, but, due to their demography, the need to build new houses to accommodate urban dwellers cannot be fulfilled with conventional materials and norms without having a significant carbon impact.

[25] Solar water heaters are a simple technology which has been mature for decades, but is still largely ignored by policymakers. Some countries like Tunisia or South Africa managed to disseminate them at very large scale. See Lemaire & Kerr (2018).

[26] https://architizer.com/blog/practice/tools/architecture-for-a-change/

which even most buildings in formal settlements ignore. Modernist building standards generate poverty and poor health (Njoh 2012: 86–91). Various delivery mechanisms of affordable housing can help the mass production of houses become more secure than self-constructed shacks (UN-Habitat 2011).

Buildings are part of an ecosystem, and acting on buildings alone is not enough. Speculation—rejecting inhabitants in suburbs where land is less expensive and fulfils the desires of families to obtain more space and security—tends to impose long commutes for work and shopping. More resilient cities implies not just new buildings but other types of ecosystems of buildings. As the ongoing COVID-19 crisis seems to be demonstrating, remote working and online shopping may become the new normal in African cities as in most European countries. Office blocks and commercial spaces are likely to be less needed and may give way to an allocation of space in the city centre to other users. Urban planning may have to completely revisit the design of the modern city due to a dramatic shift in habits.[27]

A wealth of literature has already been written on what post-COVID cities could be, and it seems urban policymakers, at least in OECD countries, have been proactive in implementing transformative actions from the very start of the crisis (OECD 2020). This new imaginary and habits of online social activities could become entrenched in African cities that are connected to high-speed Internet; but, while the use of mobile phones is widespread, only a minority have access to a computer. Deeply rooted social and cultural management norms can also intervene and derail the process of transitioning to teleworking and online shopping in countries where face-to-face relations are so important.[28]

But this debate around remote working involves employees from the formal sector. People in the informal sector have no such alternative and their livelihood, when it does not rely on providing services from their shack, implies gaining access to lively city centres and busy streets, which could come closer to where they live.

The recognition of the vernacular city is based on a recognition of the existence of low-cost/low-carbon ways of building a city where the inclusion of everyone leads to a global increase in standards of living while drastically reducing the carbon footprint of urban growth.

[27] It remains to be seen what kind of balance between remote working and office working will endure. But ecosystems built around commuting and working in city centres may never come back to their previous level of activity.

[28] In Nigeria and South Africa, the shift to remote working has been significant. To determine the future balance between remote and on-site working, the technical issue of access to reliable networks (Internet, electricity) at home versus at the office may be less important than embedded sociocultural habitus. But it seems that in the Global South as in the North, employees and employers have a mutual interest in carrying on with a hybrid mode. https://qz.com/africa/2053741/remote-work-risks-exploiting-workers-in-low-income-countries/; https://www.infoq.com/articles/working-remotely-Africa/

Low-carbon mobility—the car-free city?

As transport infrastructure cannot keep up with the territorial expansion of African cities, urban mobility is becoming a critical challenge in most cities; the transport system in Africa is quite different from that in the Global North with a prevalence of informal/paratransit modes of transport (for example, collective taxis or minibuses). But these paratransit systems are seldom taken into consideration by policymakers who focus on large infrastructure projects more than on mobility itself (Klopp & Cavoli 2019, Boutueil *et al.* 2020, Falchetta *et al.* 2021).

If mobility in a city is considered to be a major component of its efficiency, one of the constant characteristics of urban Africa is the prevalence of cars, which are, most of the time, moving very slowly. Some African cities now appear jammed with cars. The apparent paradox is that only a small minority of urban dwellers in African cities own or ever will own a car, which remains a luxury even for most segments of the emerging middle class.[29] But the choice of allowing free rein for a mode of transport that can only benefit the elite and upper-middle class is rarely questioned in African countries, unlike in Europe (Pirie 2014: 133–47).

There would be so many reasons to question this choice, which is reflected in African countries, even more than in OECD countries, as the predominance of a habitus and a status symbol more than a rational choice (or a rational choice but just from the point of view of the African bourgeoisie). Cars destroy mobility and urbanity (Pitcher & Graham 2006). First, a transportation system geared around cars implies a city built around cars with great distances between the different functionalities and services of a city—this imposes a financial burden on middle-class households who have to sacrifice a large share of their income to reimburse/buy a car, which means exclusion from mobility of the majority who cannot afford a car and have to rely on an inappropriate public transport system based on informal services from collective taxis and overcrowded public buses.[30]

Second, cars in a city create congestion, which leads to considerable wasted time,[31] environmental costs in terms of air pollution, and consumption of urban space that could be devolved to uses besides roads, car parks, and other infrastructure. The paucity of infrastructure and the lack of planning create permanent traffic bottlenecks.

[29] The number of vehicles per inhabitant in sub-Saharan African countries is far below 100 per 1,000 inhabitants except in Southern Africa.
https://ourworldindata.org/grapher/road-vehicles-per-1000-inhabitants-vs-gdp-per-capita.

[30] Even if some African cities have implemented mass public transport, the informal sector represents an important share of public transport supply: between 35 per cent and 90 per cent (Falchetta *et al.* 2021).

[31] It is not uncommon in cities like Accra or Dakar to have to spend several hours per day commuting.

Due to rapid demographic growth, a predict and provide[32] approach to accommodate cars is impossible, and cities cannot cope with the expansion of car ownership and taxis. Third, the infrastructure around cars needs a considerable investment and maintenance budget, which may be subject to corruption and market distortion, which in cash-strapped African countries could be devoted to better uses (Gwilliam *et al.* 2008, Collier *et al.* 2015); it would be cheaper to build cities around alternative means of transport that could guarantee a more fluid mass transit.

Fourth, as anyone who has lived in Africa has realised, pedestrians are often completely forgotten by planners, not only because distances intended for car use are too great to be travelled on foot in a hot climate but because there are no proper sidewalks. This is sadly one of the main reasons for the extremely high number of fatalities in the Global South (World Bank 2014). Fifth, cars kill and mutilate not only vulnerable pedestrians, notably children, but also a high proportion of drivers; this proportion is a lot higher than in Western countries due to the poor state of local roads and often second-hand cars[33] and the local norms of driving.

Last, the level of air pollution in some sub-Saharan African countries can be high, notably in the Sahel region where it is one of the highest in the world.[34] This is linked to environmental factors, increased frequency of dust storms,[35] and wood burning and in urban areas is seriously aggravated by an ageing fleet of cars that causes extreme pollution (UNEP 2020). Outdoor air pollution kills more than four million people worldwide every year;[36] small PM10 and PM2.5 particles damage the health of not only the frail and vulnerable but of everyone. This impact can only be aggravated by the extension of urban areas.

In conclusion, the lack of priority given to public transport and the de facto priority given to cars is a typical example of the promotion of an inefficient and costly means of transport in urban areas. In the case of African cities, this choice appears even more absurd than in Europe, as it is more apparent that they guarantee the comfort and the benefit of the very few and clearly go against the benefit of the majority (that is, everyone—as permanent traffic congestion means inefficiencies, even for the privileged). Furthermore, most road infrastructure is in poor condition—only main roads are tarmacked and, even in formalised areas, public transport is deficient and

[32] This approach which consists of providing more roads to meet an ever-increasing demand is considered a dead end, even in OECD countries.

[33] In Africa, the market for new cars is small and the vast majority of cars are imported second-hand via semi-official networks from Europe or Asia (notably Japan); the absence of regulation makes Africa a 'dumping ground' for cars that do not meet pollution norms in their country of origin (UNEP 2020).

[34] https://www.nasa.gov/topics/earth/features/health-sapping.html

[35] https://www.thinkglobalhealth.org/article/weathering-sahel

[36] https://www.who.int/health-topics/air-pollution#tab=tab_1

dirt roads can be impassable in the rainy season. Mobility is seriously constrained for most inhabitants in African cities and the Automotive City in urban Africa represents an ideal of modernisation that is obsolete even before its full realisation.

Cities built around cars are particularly non-adapted to a changing climate: the level of air pollution can be deadly when temperatures rise; the tarmac of roads and the multiplication of thermal engines combined with the concrete of buildings create heat islands; the impermeability of roads increases flash flooding; dust from non-tarmacked roads and the level of noise in the streets combined with the multiplication of high-rise structures blocking air flows prevent natural air-conditioning of buildings, since windows cannot be left open.[37]

With COVID-19, there has been a multiplication, particularly in OECD countries, of 'urban guerrilla' operations/tactical urbanism to reduce public space for cars and air pollution (Carmichael 2020): a reduction in the size of roads and streets allocated to cars is giving space to cyclists, electric mopeds, and scooters to make city centres pedestrian-friendly while planting trees and increasing green spaces. In short, building cities around the needs of humans can help them to be more resilient to climate change, as represented in the future of post-COVID cities. Until now, few African cities have embraced the concept of a car-free city, even if some African countries are now adopting monthly car-free days.[38] Mass transit relying on high-capacity buses with dedicated lanes—Bus Rapid Transit—has just started to be successfully developed in South Africa; Africa is lagging far behind Latin America. The development of urban rail systems is, nevertheless, gaining traction in major African cities, with many projects under construction.[39] Addressing social inequalities in transport would imply making a clear choice in favour of collective public transport and soft low-cost modes of mobility and getting away from the supremacy of the car. Low-cost/low-carbon (public transport/electric scooters)[40] approaches goes with equal access and the democratisation of public space for everyone and against high-cost/high-carbon (the conventional car) or high-cost/low-carbon technologies (the electric car) which will remain in African cities the perk of the few and may lead to competition for scarce resources.

[37] Their isolation from the environment could be presented as a necessity due to the presence of IT devices—computers do not like humidity and dust.

[38] https://www.unep.org/news-and-stories/story/car-free-days-are-taking-hold-african-cities

[39] https://www.railwaygazette.com/news/regions/africa

[40] Public transport may imply substantial investment, but its cost per passenger/km is low due to the high volume of passengers carried.

Occupation of space—the recognition of informality?

The occupation of urban space in African cities is a mix of standard urban planning that segregates people according to their social class/wealth and large areas of spontaneous informal settlements relegated to the margins of the official organised space but where the majority of inhabitants live. The post-colonial history of the urbanisation of African cities reveals that the authority's approaches constantly oscillate between 1) ignorance of informality, 2) eradication of informality by bulldozing informal settlements and policing informal activities, and 3) recognition of informality by upgrading informal settlements and enforcing light regulation of informal activities. However, ignorance and eradication seem to prevail and can be particularly ruthless.[41]

Definitions of what is informal are far from established (Coquery-Vidrovitch & Nedelec, 1991, Simone & Abouhani 2005: 237–8). Informal could essentially mean not informed by official directives from urban planners who consider with suspicion any spontaneous organisation from inhabitants who have to invent viable lives for themselves; informal settlements are actually socially organised even if they appear chaotic in the eyes of outsider/official planners, the latter sometimes being complicit in the not-so-spontaneous organisation of the informal urban space (Coquery, 1991: 197–203, Myers 2011: 71–8).

Furthermore, boundaries between officially organised space and informal chaotic space are blurred; even within officially organised urban spaces, informality can be found—that is, non-compliance with official rules: street vendors along main roads, backyard dwellers, and the subletting of rooms. Informality is everywhere in urban Africa, but this informality is rarely recognised by authorities who still tend to perceive it as a necessary evil part of African life or a failure of their official policies. The latter, by imposing rules that cannot be observed, create informality, which is being used as a power resource by the well-connected.

New forms of occupation of space in African cities mean better transparency and the democratic inclusion of informal urban forms, and a break with the persistent old reflex of attempting to erase or ignore informality. This applies particularly to informal constructions but also to street vendors and any other not officially agreed occupation of urban space.[42] New forms of occupation of space in Africa can only emerge if the

[41] For instance in Nigeria (Nuvanna 2015) and Zimbabwe (Potts 2006); in Francophone Africa, operations of eviction called '*déguerpissements*' are also quite common.

[42] Streets in Africa are an extension of houses: places where people live and work and not just public space where people circulate. This is particularly true in informal settlements, as shacks are very small and inhabitants are used to managing their immediate surroundings without relying on municipalities; their involvement in the self-organisation of their living areas does not stop at the door of their house (Khalil *et al.* 2018: 71).

capacity for creation and survival skills of inhabitants are recognised by authorities. It also implies recognising the influence of the past and a break with the heritage of colonialism still pregnant in Africa in the structuration of ideas (which translates into concrete constructions). What is a modern rational city in Africa based on a representation of an orderly city (that is, a city reinforcing colonial dominance) mobilising prejudices and racist bias?

The heritage of French, British, Portuguese, Belgian, German, Spanish, or Italian colonisation remains apparent in African cities with the structuration of streets in rectangular patterns and colonial buildings (now often in a poor state, left to squatters, and earmarked for future speculative redevelopment). Areas formerly demarcated during colonial times for the indigenous population and segregated from colonial quarters can also still be seen in the urban fabric: they were places where manpower would be available but under the social control of the Europeans. They include new areas with the construction of basic houses (townships) and the conservation/demarcation of native quarters with their traditional construction; native quarters were perceived as unhealthy for Europeans, and inhabitants were deliberately left to their own fate and had to self-construct their houses (Coquery-Vidrovitch, 1991: 174–7).

Post-war master plans inspired by Le Corbusier's ideas of zoning aimed to create new intermediate neighbourhoods where an African urban educated elite and European middle class could live (Dalberto *et al.* 2013: 43–64). Immediate post-colonial urbanism has added a structuration/hierarchisation of space according to the income of inhabitants with the highest luxury standards of construction, with the best location for the elite and then a progressive diminution of standards as social status lowers (Massiah & Tribillon, 1987: 52–5). Post-independence master plans designed by international consultants have only reinforced and entrenched such colonial practices (Cobbinah & Darkwah 2017). This segregation has been amplified with a reduction in public intervention in the 1980s. Private developers are now in charge of the construction and expansion of the official city with limited oversight from municipalities. New social housing programmes tend to be scarce; private developers trying to maximise their profit are logically targeting, as a priority, inhabitants with some or high purchasing power.

Migrants and the poor are more than ever being left to their fate with no official property titles and, therefore, under the constant threat of eviction in places that are more often prone to flooding, landslides, and fire hazards.[43] The density of population in informal settlements can be high, causing limited access to basic services like water, sanitation, transport, and electricity, which means rubbish is dumped or burnt

[43] In the most rudimentary shacks, fire is a major hazard which can wipe out whole quarters; this is either due to accidental causes linked to the use of cookstoves and petrol lamps … or it can be intentional as a way of pushing people to move out (Jones 2020: 148). Flooding is often considered as the major threat from climate change by the inhabitants of informal settlements (Busayo *et al.* 2019).

everywhere, so conditions of hygiene can be deplorable, and the sense of insecurity is high. The multiplication of extreme natural events aggravates the precarious conditions of inhabitants living in informal settlements and, by extension, to those living in nearby neighbourhoods.

Climate adaptation would mean prioritising the reallocation of urban space according to differentiated risk zones. Allocating space for the poor in safe areas seems like a prerequisite instead of leaving vulnerable areas to vulnerable people who, in the current economic system, unavoidably occupy the interstices left where no developers can go because of the risk of flooding or landslides. This would mean pricing the land according to social and environmental criteria instead of leaving the allocation of space according to conventional market mechanisms. It would mean tackling the complex question of tenure insecurity as inhabitants living in a transient space are unlikely otherwise to invest time and money in building resilience and a political project in a specific place if they could be under the threat of eviction at any time (Simone & Abouhani 2005: 10–24). In terms of land tenure, public authorities need to deal with non-statutory authorities, and transactions remain largely opaque (Simone 2004: 192–201, Magigi & Drescher 2010, Kleeman *et al.* 2017). The privatisation of rights has led to a new customary land tenure with new relations of power, which have led to further marginalisation of the poor, who relied on informal networks and now find themselves more and more in competition with outsiders (Myers 2011: 83–6, Chimhowu 2019). In those conditions, control of urban allocation for climate adaptation means establishing a dialogue with communities. Climate adaptation of informal settlements also implies acting not only on buildings but also on the informal economy in general (Table 1).

The recognition of informality by giving support to the majority of inhabitants who live in an informal way instead of a minority could enhance and make more sustainable and rewarding already-existing low-cost/low-carbon ways of inhabiting the city and help to build a low-carbon expansion path for the city.

III. The mobilisation of the human resource

Communities and environmental management

The impact of climate change felt differently by social status implies different strategies of adaptation for different areas of a city (Table 1). Informality is a synonym for over-occupation, high density, and narrow streets, which renders external emergency intervention perilous due to difficult access. The absence of a proper sewage system, the lack of drains, and drains blocked by non-collected waste contribute to an increased likelihood of flooding and diseases in areas located in vulnerable zones.

Table 1. Likely impacts of climate change on informal settlements and possible measures to adapt. Source: UN-Habitat (2018).

Projected changes	*Examples of likely impacts*	*Implications for residents of informal settlements & people working in the informal economy*	*Possible measures to adapt*
Higher (and increasing) average temperatures, more hot days and heat waves, fewer cold days — over nearly all land areas	Rise in mortality and illness from heat stress in many urban locations. Extended range and activity of some disease vectors — including mosquito and tickborne diseases. Increased water and energy demand	Many informal settlements are very dense with very little open/public space and often with uninsulated corrugated iron roofs and poor ventilation that contribute to higher indoor temperatures. Lack of public health measures to control disease vectors. Largest impacts among groups particularly vulnerable — infants and young children, the elderly, expectant mothers, those with certain chronic diseases. Health risks for outdoor workers and informal workers may not benefit from health and safety regulations	Improved building design to maximise natural ventilation; set up locally accessible health services; provide education about measures to reduce transmission of disease and reduce risk of heatstroke/cold exposure. Investing in green space, renaturation and tree planting
More intense precipitation events and riverine floods	Increased flood, landslide, avalanche and mud-slide damage resulting in injury and loss of life, loss of property and damage to infrastructure. Increased flood run-off often brings contamination to water supplies and outbreaks of water-borne diseases	Many informal settlements concentrated on sites most at risk of flooding with poor quality housing less able to withstand flooding and a lack of risk-reducing infrastructure. Homes, possessions and income-generating assets are not covered by any public or private insurance. Transport infrastructure damaged affected workers	Building and infrastructure designs that incorporate flood and landslide resilience; improve drainage infrastructure locally and city flood management practices and systems; innovate to identify suitable disaster insurance products
Wind storms with higher wind speeds	Structural damage to buildings, power and telephone lines, communication masts and other urban infrastructure	Relatively small increases in wind speeds can damage buildings, particularly as many informal settlements are composed of temporary or semi temporary housing. Also, informal utility services are likely to be damaged or cut due to extreme wind	Improve housing design and construction to withstand winds; improve construction and design of infrastructure
Increased summer drying over mid-latitude continental interiors and associated risk of drought	Decreased water resource quantity and quality; decreased soil quality and risk of soil erosion; increased risk of forest/bush fire; decreased crop yields and higher food prices	Informal settlement residents usually facing more water constraints and are more vulnerable to food and water price rises	Addressing underlying socio-economic factors which affect poverty; improve water infrastructure and affordability
Intensified droughts and floods associated with El Niño events in many different regions	Decreased agriculture and range-land productivity in drought-prone and flood-prone regions	Impact on food availability and prices in urban areas	Promote rooftop or urban gardening to supplement food sources. Strengthen livelihoods to increase incomes
Sea-level rise	Coastal erosion, land loss, more floods from storm surges; hundreds of millions of urban dwellers living in low elevation coastal zones	Many informal settlements close to the sea with poor quality housing and lacking drainage infrastructure	Raise awareness of storm surges; construct protective infrastructure or explore relocation in a participatory manner

However, informality also means human resources and indigenous knowledge that, when mobilised, could help to increase resilience to climate change. Coastal erosion, landslides, and floods can be partly prevented by direct action from inhabitants as long as they receive some kind of support from authorities. Effective alert systems and disaster risk management need the full participation of local communities who possess the knowledge of the area in which they live (Kasei *et al.* 2019).

African cities need protected green spaces and green corridors to act as buffer zones and mitigate the impact of natural events and also to contribute to the well-being of their inhabitants. Green spaces and trees along streets have multiple benefits in terms of climate adaptation: the prevention of landslides and flooding, reduction of heat islands,[44] generation of income, and multiple services (Lwasa *et al.* 2013; du Toit *et al.* 2018). It is widely recognised that a healthy city implies a closer contact with nature and moves away from a predatory model to biophilic design and biomimicry (Chatterton 2019: 74–81); but, in most African cities, access to urban green infrastructure, notably for the poor, tends to diminish rapidly (Mensah 2014, Roy *et al.* 2018, Venter *et al.* 2020). Designated non-constructible zones do not remain without construction for long if buffer spaces created on paper are not benefiting local communities who then have no interest in protecting those areas.

Conservation areas are one possibility for providing green space, but only if combined with sustainable exploitation of forests, for the extraction of wood, urban agriculture, or recreational use. Environmental management would need to be more integrated (Cilliers *et al.* 2014, Padgham *et al.* 2015, Douglas 2018), as in rural areas, where instead of strict conservation areas opposed to development areas, mixed use is now being promoted (Andrade & Rhodes 2012). Boundaries in urban areas should not be used to enforce strictly protected zones, but should favour mixed use with a progressive change of use.

This implies new forms of environmental management where concerns of local communities are part of the solution and not sidelined (Lindley *et al.* 2018), less short-term thinking where market forces are prevalent, and more long-term planning, as land speculation does not recognise the value of non-built spaces. By giving their inhabitants control over their immediate environment which is then managed for and by local communities, and by letting local solutions emerge and complement large infrastructure discussed with local authorities, the risk of systemic failure of complex cities can be reduced (Satterthwaite 2011a).

From elusive to effective participation

Community participation is recognised as a way to favour inclusiveness by allowing the poor to explain what their priorities are; to mobilise people who will recognise solutions as theirs because they are co-designed by them and grounded in their

[44] In a survey conducted in informal settlements in Cairo, planting trees was the preferred low-tech, low-cost strategy to reduce heat islands followed by the use of facades, light-coloured painting, roof planting, fabric sheds, and wooden pergolas (Khalil *et al.* 2018: 71).

reality;[45] to make public services and administrations work together; and prioritise and promote integrated solutions because the community's needs are a common focus (Cobbinah *et al.* 2019, Leal Fihlo *et al.* 2019).

The idea of participation has evolved considerably from providing manpower to pre-established projects to empowerment, and the degree of openness of municipalities to civic participation can fluctuate (Burgess *et al.* 1997, Sarzynski 2015). But, if participatory planning has been a leitmotiv in the field of urban planning since the 1970s, it has led to few long-lasting achievements in urban Africa, as emerging effective demand-led partnerships driven by local communities with municipalities, the private sector, and donors still remain constrained, even if more and more recognised by all as a necessity in the face of an accumulation of risks (Leck *et al.* 2018). Community-based adaptation to climate change, which emerged at the beginning of the century, still needs to be upscaled (Okpala 2009: 20–2, McNamara & Buggy 2017). There are multiple reasons for this: community participation takes time to put in place; donor aid projects have a limited life-cycle; turnover within municipalities and donor organisations can be high; delimitation of responsibilities remains unclear—all these factors leaving communities without clearly identified interlocutors.

Opacity of power is also a condition of power for some stakeholders. Participation implies power and knowledge sharing, which is difficult to conceive for politicians and technocrats who consider themselves as unique possessors of decision and planning capacity; participation also needs to answer the question of who to engage with, as community leaders often fail to represent the most marginalised and women (Lemaire & Kerr 2017a) and participation itself can lead to an exclusionary/marginalisation process or participation following an already-established agenda (Aylett 2010, Rigon 2014, Fredericks 2018: 101–21).

This could be avoided by greater institutional stability and brokers between the official world and communities spending time to understand local dynamics of power and reach out the voiceless; it implies combining knowledge that has been produced by participatory methods and action over time to 'reinforce the alternative forms and categories of knowledge which might have been produced' (Gaventa & Cornwall 2006: 126). And perhaps the key issue for international donors is to recognize the need for their long-term engagement in supporting a national (and in some nations a provincial) system that builds adaptive capacity by local governments and civil societies (Satterthwaite 2011b: 774).

In the urban field, participatory planning goes against a well-established inclination among African urban planners to take authoritarian top-down measures for the

[45] Case studies are a good method to achieve this (Duminy *et al.* 2014a) as the use of participatory mapping.

benefit of the few (Duminy *et al.* 2014b). Cooperation with local leaders in informal settlements would imply recognition by local and central authorities of alternative forms of development and the freedom of inhabitants to create and possess vernacular knowledge. But, on the contrary, urban planning in Africa has been since the beginning a (desperate) attempt to bring some order into what is perceived as pure chaos. Effective urban participatory planning (that is, empowered participatory governance, which involves rethinking the whole decision-process and the public arena) can produce results and succeed in providing basic infrastructure and services in different contexts (Sclavi 2008).[46]

In the case of the complex implications of adaptation to climate change, decentralised solutions where communities get involved seem preferable to any central solution, particularly in an African context where municipalities are so overstretched financially and in terms of human resources that they cannot do everything themselves. The pace of change needed to adapt to the new conditions created by climate destabilisation cannot be achieved without the active participation of local communities. However, as, until now, African cities have been manufactured by a mix of authoritarianism and *laissez-aller*, there have been only rare occasions of dialogue between planners, developers, and communities.[47] The creation of common spaces of permanent dialogue would seem like a prerequisite to addressing the multidimensionality of climate change impact—municipalities can only lead the way by learning how to catalyse innovations and help solutions to emerge[48].

Participatory planning—co-deciding new adapted infrastructures and new urban schemes—could lead to the participatory management of services and help to guarantee the sustainability of any new investment by reducing the cost of its maintenance. However, the mobilisation of communities on a voluntary basis may have its limits; sustainable services can only survive with a strong collective commitment and if someone is in charge and being paid for their time. Local communities are not immune from exploitation by self-proclaimed leaders, and slum inhabitants often have to pay bribes for substandard services to dubious intermediates with connections to corrupt local politicians (Murray 2008: 115–19, 135–9).

[46] There are multiple ways to favour inclusiveness when it comes to urban planning (Lemaire & Kerr 2017b). Electrification and waste management are good examples where the formal can be articulated to the informal via participatory inclusive processes (Lemaire & Kerr 2016a, 2016b, Simatele *et al.* 2017).

[47] On that matter, small cities may have less access to financial resources and international networks but stronger networks 'within the city', as local elites know each other and have to work together (partly to compensate for the lack of resources). See Pasquini (2020).

[48] Action planning tools are being developed by UN-Habitat to favour sharing and inclusive decision process. See Spaliviero *et al.* (2020). Existing modelling tools like LEAP can also be used as a way to bring stakeholders together and develop a heuristic approach. See SAMSET http://samsetproject.net/

An alternative is an idea well known in the fashion of public–private partnerships, as the multiplication of private initiatives does not lead to any change without some kind of public support. The emphasis on public–private partnerships is presented in the international aid sphere as the solution to problems that fifty years of international aid have not been able to solve. However, the term public–private partnerships covers different types of partnerships with different types of partners—to partner with small enterprises or local cooperatives is not the same as partnering with large corporations. This is often the latest disguise of privatisation and dispossession of the poor.

In the case of cities, municipalities as public agents could be supporting and coordinating local grass-roots private initiatives and regulating the activities of big providers. Cases of successful inclusive partnerships and integrated plans in urban Africa seem quite rare.[49] Particularly in the case of adaptation to climate change, this constitutes a handicap as it seems almost impossible to identify and implement climate adaptation measures in a centralised manner.[50] The creation of local economic systems based on the multiplication of small grass-roots initiatives scaled with the support of municipalities would transform challenges in inclusive business opportunities; this is particularly true for markets which can be created with relatively low entry barriers in terms of capital investment, where small-scale operators can complement the activities of large corporations; instead of trying to regulate and formalise the activities of small-scale operators, local authorities can help them to sustain their activities by creating platforms guaranteeing access to micro-loans and knowledge transfer, and protect them from over-exploitation by the formal sector (Lindell 2010, Brown *et al.* 2014, Lemaire & Kerr 2016a, 2016b, Akinsete *et al.* 2019).

[49] Most cases can be found in Latin America (Satterthwaite 2011a). For an example of the limits of participation in not-so-democratic political regimes, see the example of waste management in Tanzania and Zambia (Myers 2005). Even in a relatively democratic open regime like that in Senegal, participation may be encouraged but only to some extent as higher levels of government remain inaccessible (Vedeld *et al.* 2016, Leclerq 2017).

[50] Some 'early adopter' municipalities in South Africa (like Durban and Cape Town) have more than a decade of experience of integrated development plans taking into account climate change with a growing emphasis on community-based adaptation. For a perspective on the case of Durban, see the work by Roberts (Roberts 2008, 2010, Roberts & O'Donoghue 2013, Roberts *et al.* 2016). Nevertheless, even in Cape Town, climate change measures cannot be considered as fully mainstreamed into municipal planning instruments (Taylor 2016, Hickmann & Stehle 2019, Pieterse *et al.* 2021).

IV. The process of change

Competitive ideologies

The most difficult part of any change is not just to have a vision and share it, but also to pose principles of action based on existing realities. There are different stages in any innovation process. Currently, African municipalities participating in an increasing number of regional and international networks are in the phase of exchanging knowledge (Watson & Odendaal 2012, Kuinsi 2016, Castán Broto 2017, Ndebele-Murissa *et al.* 2020). This phase of dissemination of best practice and case studies forms a corpus of novel ideas (Odendaal 2012, Duminy *et al.* 2014a). But the exposure of a few people to new ideas is not enough. A critical mass of individuals sharing those ideas is needed, and local actors need to build their own networks in their countries (Scott *et al.* 2019).

Building a permanent forum of exchange with channels of communication opened by local communities/organised citizens groups is, as mentioned before, another prerequisite 'to go beyond the conventional confrontational protests' by which the urban poor seek to influence the government (Satterthwaite 2008) to co-production to access basic services (Mitlin 2008, Fatti & Patel 2013).[51] One difficulty is to retain the momentum around any new initiatives (Roberts *et al.* 2016). Money is an issue and projects need to be sustainably funded; hence the requirement for private local partners that have more flexibility than public administrations and that can raise money for effective service delivery. However, the main obstacle to overcome is, as usual, the existence of complex systems of vested interests with powerful actors who benefit from planning as it is and have no interest in changing the status quo (Watson 2009). Corruption and clientelism are, by nature, not open to any exercise of transparency and so-called good governance, even under the pressure of international NGOs and donors (Gandy 2006).

Furthermore, climate change—even if it has already had a detrimental impact on the everyday life of inhabitants of African cities—could be perceived by the majority as one problem among many, even if perceptions seem to be rapidly changing.[52]

[51] Slum Dwellers International, which is a global network of federations of urban poor communities, promotes the idea of militant negotiation (https://sdinet.org/, Dobson 2017) and now has a number of federations in African countries, notably in southern Africa. For the action of a federation in Uganda, see Dobson *et al.* (2015).

[52] The poor in the Global South are perfectly aware of climate change, contrary to the patronising presentation made in the Global North and by partisans of the status quo in the South, but they have their own perception of a changing climate. See, for instance, McQuaid *et al.* (2018). Inhabitants of towns along the river Senegal, whose livelihood is directly dependent on weather patterns, have to develop a practical knowledge of climate change (personal interviews, 2020). Climate change is now be perceived as a great threat among policy-influencers in southern African cities (for instance, Steynor *et al.* 2020).

The emphasis placed by international donors on mitigation measures may be perceived as an example of neocolonialism, as Africans are minor contributors to greenhouse gas emissions; actually, only a minority of urban inhabitants are yet aligned to the same consumption norms as the middle class in OECD cities.[53]

Effectively, renewable energy technologies, soft modes of transport, urban agriculture, and smart cities could easily be caricatured as imported ideas, reflecting first and foremost the concerns of the Western middle class and far from the day-to-day realities of Africans. But actually some of these 'mitigation measures' like urban agriculture[54] or soft mobility are not new in African cities, even if they often lack official recognition; they contribute to climate adaptation while preventing African urban inhabitants from becoming high emitters of greenhouse gas emissions.[55] Some technological fixes could, nevertheless, have a limited impact if they remain perceived as off-ground and do not benefit from local support. Another movement of ideas of so-called intermediate technologies, supposedly more adapted to local realities, has also been categorised by local politicians as a tentative step to keep Africa underdeveloped.

Furthermore, the habit of not listening to local communities—except before election time—is anchored in local practices. Endemic corruption in most African countries hinders the delivery of resilient urban infrastructure and services (Chirisa *et al.* 2016).[56] Local politicians can gain more symbolic power and personal monetary rewards by continuing to invest in large-scale infrastructure like highways and roads, central electricity plants, and large waste treatment plants, and may see any alternative paths as useless or as a direct threat to their position of power. The perpetuation of the current system, excluding the majority, is a resource rather than an issue for them, and the protection of the poor and most vulnerable against the impact of climate change could be the very least of their concerns (Satterthwaite 2011b).

[53] Mitigation measures promoted by international donors instead of adaptation measures transform climate change into an external problem promoted by external actors with their agenda and their technological solution, reflecting a hierarchy of values and priorities that are far from the concerns of local inhabitants.

[54] Kampala and Nairobi are cities where urban agriculture has been successfully promoted and upscaled (Gore 2018). Urban agriculture is practised by 50 per cent of households in Kampala and is more and more recognised by authorities (Vidal-Merino *et al.* 2021). But in many African cities, urban agriculture remains an illegal practice or is just tolerated as a temporary use of land (Simatale *et al.* 2012: 1187–8, Titz & Chiotha, 2019).

[55] African municipalities are simultaneously engaging with mitigation and adaptation measures (Aylett 2015: 8).

[56] But not all of them and not at the same level, contrary to a vision tainted with racism on Africans—every African country, on that matter, is different. See, for instance, the difference between urban planning enforcement in Uganda and Rwanda (Goodfellow 2013).

Adaptative action to climate change means a shift in the balance of power, which will come from activism and grass-roots initiatives (Ziervogel 2019). Data collection and bottom-up participatory mapping can help to make informal activities more visible and give grass-roots actors a legitimacy to participate in the planning process by recognising the existence of informal settlements (Vergara-Perucich & Aris-Loyola 2021), paratransit systems (Klopp & Cavolli 2019), or any other informal activities. Action means differentiated strategies according to the context that evolves within each community. Urban guerrilla operations, which go with the re-appropriation of public space, and participation in local political assemblies, protests, and petitions, have been proven to enable change by eroding the legitimacy of established actors promoting conventional infrastructure, which is nothing more than artefacts from an outdated ideology of progress.

Actions grounded in existing urban morphology

The temptation of the *tabula rasa* may always be strong among some urban planners and architects, either because the elements of modernity implemented in African cities seem inadequate to sustain any long-term future or because informal settlements do not fit into the representation by the policymakers of the future of their city (Kloosterbooer 2016: 62–70). The building of entirely new towns has met with variable success (Abubakar & Doan 2017, Keeton & Provost 2019). Gated communities and futuristic cities built from scratch and mobilising private investors lead to enclaves of prosperity, which represent the antithesis of urbanity (Lemanski 2006, van Norloos & Kloosterbooer 2018).

As much as it is not desirable to eradicate informal settlements or constructions erected during colonial times, it does not seem desirable or possible to erase modern buildings that have been built since independence, even when these buildings are aesthetically dubious, inefficient, and costly to maintain. As the stock of buildings can last more than a hundred years, the urban mix of old and new can only be adapted rather than eradicated. Tighter regulations can apply to new constructions only with the active participation of inhabitants who can apply some form of social control and assist public agents, who are too few to enforce them. These regulations should be clear, easy to follow, adapted to the tropical climate, and not a direct transfer of EU regulations. Otherwise, if complicated and disconnected from local practices, the high number of new constructions, which are being built every year, will continue to be built according to the lowest standard.

Retrofitting of the old stock of buildings could give priority to low-cost high-impact measures that help to insulate buildings and adapt them to extreme events. Meanwhile, the poorest living in informal settlements could be targeted first with measures that are relatively easy to implement. A good example is the ceiling retrofitting insulation programme in South Africa, which can protect shacks from heat and cold for a small investment (Kirsten 2015, Kimenia *et al.* 2020). Different energy and environmental audits of the existing stock of buildings and existing infrastructure need to be completed to give a clear picture of the key actions to be achieved in each area; these audits need to be conducted with inhabitants and local communities and their conclusions discussed with them.

Action on buildings should be conducted simultaneously with action on their immediate environment, like easier-access paths to replace narrow paths in informal settlements, a proper drainage system, and the creation of community-managed buffer zones (Table 2). Again, this cannot be achieved with poorly defined objectives but needs to be done with and for local communities.

Table 2. Paths toward low-carbon cities.

Current issue	*Aim*	*Example of paths*	*Main obstacles*
Carbon-intensive buildings to build and maintain	Use of low-carbon local materials; use of decentralised renewable energies; passive design	Low-carbon building standards; nomination of energy managers in large buildings; provision of materials for self-construction	Mindset in the building industry and among contractors; wealth inequalities
Investments geared toward infrastructure promoting carbon-intensive mobility	Transfer to low-carbon collective or soft mobility	Reorientation of infrastructure investments; inclusion of cyclists and pedestrians in decision processes	Local producers marginalised in favour of importers/foreign companies; social status affirmation and preservation
Informal sector/ informal settlements ignored or seen as a nuisance to be eradicated	Integration of informality to provide support and increase resilience	Creation of public platforms of exchange between officials and communities—support to self-organisation movements; attribution of land rights	Mindset of policymakers; contempt for the poor; research into status quo in keeping wealth inequalities
Deterioration of quality of life linked to chaotic urbanisation	Protect and maintain the environment of local communities	Support for the active management of the immediate environment; effective participation in the design and management of green spaces	Ignorance of local communities' knowledge; land speculation
Top-down urban planning with exclusive planning practices	Inclusive planning practices favouring a bottom-up approach	Integration of local communities in the planning process at every stage of planning	Authoritarianism and contempt for citizenship; urban dwellers as subjects ruled by traditional leaders

Conclusion: inclusiveness or disintegration?

Climate adaptation in an African urban context may aim to implement the same ideals of a post-COVID city as in other cities in the world: a city that promotes the well-being of its inhabitants instead of a focus on economic competitiveness, and the promotion of resilience instead of an illusion of wealth due to the unsustainability of the current economic system. The ideology of urban competitiveness and world-class cities implies nothing less than a permanent war on the poor (Huchzermeyer 2011: 47–68).

African state officials have been, since independence, in denial of the importance of urbanisation. Cities are being viewed as places of unrest and contestation of their power, and they prefer to focus their investment in rural areas. Post-colonial urban planning in Africa has failed to address all the major issues faced by urban dwellers, who often need to fend for themselves in a hostile administrative environment that is incapable of providing them with elementary services. Local authorities and their enforcement agencies are, in most cases, the enemy, and communities have to continually negotiate their survival. Even having the ability to secure a land plot/parcel is an inaccessible dream for the majority.

Urban areas would be easier to manage in a decentralised manner than by a centralised authority, which implies decentralisation/devolvement of public authorities and empowerment of local communities; however, decentralisation in Africa has often failed to give real power to local urban governments (Okpala 2009: 19, Smit & Pieterse 2014: 148–66, Wisner *et al.* 2015, Tait & Euston-Brown 2017, Resnick 2021). The informal and unplanned manner in which African cities are rapidly growing would imply the channelling of the energy of its inhabitants, and a different approach to planning where old-fashioned participation in projects designed by consultants leaves systematic ways for community enablement, with co-design and co-management of urban space in a transparent democratic manner in the pursuit of a radical agenda (Pieterse 2008). The creation of commons seems like a prerequisite: they can be based on common locations more than ethnic groups, as urbanisation should at some point allow transcendence of ethnic divisions.

Climate change brings a new dimension to the issues faced by African cities. The African context means that the impact of climate breakdown adds to already serious and seemingly intractable challenges, while urban planning practitioners are (deliberately or not) turning their backs on the majority of the population and, therefore, are unable to answer their basic needs. The urban crisis that African cities are facing can only be exacerbated by the climate crisis, and inclusive planning approaches are urgently needed, if large parts of African cities are not to be abandonned to their fate with shrinking ghettos of functional areas.

Urban development, which has taken place naturally along major rivers and the coast, means some cities may completely disintegrate. Others will have more and more difficult access to clean water and enough food supply affordable for the majority. The extreme sensitivity of the most vulnerable inhabitants to food prices is aggravated in cities where the densification of dwellings does not allow self-subsistence farming; some urban areas are again more vulnerable than others. Individual resilience has its limits. Inhabitants have some capacity of adaptation to climate change at an individual level or a community level (Kareem *et al.* 2020). They can mitigate the impact of flooding by organising the clean-up of drains, they can protect their houses from storms by reinforcing their roofs, and they can keep or establish networks with social relations in rural areas to allow the transit of food. Nevertheless, private initiatives which constitute the majority of action to prevent short-term climate variability cannot compensate for a complete lack of planning in response to long-term climate change (Hunter *et al.* 2020, Mashi *et al.* 2020). On the other hand, municipalities have limited capacity for intervention. Institutional adaptation is needed to scale-up good practices of adaptation at a micro-level (Lwasa 2010).

Measures to adapt to climate change are partly similar to measures to mitigate climate change. This implies a shift away from the carbon-intensive lifestyle as a mode of existence for the happy few or as a dream for the poor: the original ideal of *suburbia* with orderly lines of individual houses and malls relying on intensive consumption of natural resources with artificialisation and disconnection with the environment, which has been an agent of urban growth in the US (Rome 2001), is already taking different forms in the Global South. Urban policies may need to acknowledge that evolution (Keil 2018). But planetary suburbanisation with a long commute to reach places of work cannot be expanded indefinitely around the world, while it is being contested in Western countries. Reducing the need for commuting by mixing urban functions is needed; otherwise shifting the complexity of a city to its periphery is likely to continue.

The question of which city model is desirable needs to be explored concomitantly with the question of which model is practically reachable while considering the realities in which African municipalities evolve. Strategic low-carbon urban planning in sub-Saharan Africa implies clarification of what are the most robust adaptative solutions to climate change and how to implement them in a context of financial poverty and weak governance.

Climate adaptation could mean a car-free city with easy on-foot access to all the basic functions of a city and nature. But the idea of a car-free city where all services needed can be reached by walking may still have a long way to go in the imaginary of African decision-makers, for whom cars are synonymous with modernity. Low-cost/low-carbon mobility could, nevertheless, be particularly adapted to African cities.

Existing African cities have limited established infrastructure, which could prove to be an advantage as this gives greater freedom to follow low-carbon pathways. Adaptation measures could easily rely mostly on the large-scale dissemination of existing and proof-tested low-carbon socio-technical solutions, but this implies a deviation from the high-carbon pathway followed by Western cities that would remain inaccessible for the majority of African cities. It may mean embracing new technologies, new materials, and new urban forms but only as long as they can be socially embedded. This implies the rejection of top-down approaches, quick technological fixes, and artificial modernisation, replacing them with bottom-up approaches, mature socio-technical solutions, and grounded modernisation.

A hybrid combination of modern technologies and traditional materials—a modernised tradition leading to vernacular forms of construction—seems like a concrete utopian and realistic near future, as all the elements are in place. However, as the move to vernacular forms of building needs to be part of the change of a whole ecosystem, this includes a shift to new forms of mobility and occupation of urban space. In brief, it requires the acceptance of ways of thinking in urban planning more in phase with local resources and local human capacity, instead of neoliberal-inspired urban planning that keeps so-called world-class cities off-ground and off-context, enslaved to an ideology where cities are seen as in permanent competition in a global world, and the poor remain disposable and removable at will[57] (Njoh 2009).

The reinvention of the vernacular African city means the auto-creation of lasting sustainable solutions, which does not imply sacrifice but an adaptation of certain lifestyles of a minority and the mobilisation of communities. But the current mindset of urban planners and city officials in search of beautification of the city by making the poor invisible are a significant obstacle for any transition.

If African cities need to move towards low-carbon strategies generically, in a similar manner to those proposed in the cities of the Global North, the way to implement low-carbon solutions has to be adapted to the particular context of African countries: socio-technical differences linked to financial cost considerations and cultural and social differences linked to the particular morphogenesis of African cities mean that a low-carbon urban development has to follow a different path from that of Western cities. African cities currently do not emit the same level of greenhouse gas emissions as their Western counterparts and, therefore, have a specific path to follow by adapting to climate change while retaining a low-carbon footprint. Instead of having to drastically reduce their carbon footprint, they must prevent the adoption

[57] The gentrification and beautification process of cities is not particular to African countries. For an example of neoliberalism and contempt of authorities for the poor in two Asian countries, see Abeyasekera *et al.* (2019).

of a high-carbon footprint by the majority and avoid a mimetic effect by reducing the carbon footprint of the burgeoning upper-middle class.

Indeed, sustainable transition has a different meaning for informal settlements and for middle-class and upper-class areas. The first have a low-carbon lifestyle, little economic power, and limited access to political networks: adaptation means mobilising community resources—climate change adaptation is a constraint among others and inhabitants of informal settlements are used to constant adaptation. For the second, transition measures can be somehow similar to the ones taken in OECD countries as these social classes tend to have a carbon-intensive lifestyle, have economic power, and benefit from the recognition of the state or the market (Satterthwaite 2011c). For them, adaptation to climate change can always be done by mobilising capital resources to protect their assets and/or they can migrate to another country. Alternatively, to keep the city liveable, they would have to reduce their urban footprint without 'sacrificing' much, except status symbols; but this abandonment of status symbols may be not conceivable.

Some mitigation measures are also adaptation measures as they reduce the impact of climate change; but more specific adaptation measures are also needed to complete the transition. A well-targeted policy of transition toward a low-carbon city would need to be inclusive and capable of mobilising communities in the long term; the transition to a low-carbon and resilient city would involve some financial resources, and a shared knowledge and methodology; this is not out of reach of African cities even with their limited resources, as the main issue for African cities is actually one of governance. Money scarcity may not be the main constraint, as endogenous financing solutions exist to raise funding (Paulais 2012). Actually the main constraint for African municipalities lies at an institutional level in recognising climate change as a priority and integrating the actions of various departments and stakeholders in order to mobilise existing resources effectively: this implies a change in working methods to favour the coordination and exchange of data between administrative departments and with external stakeholders (Roberts 2010, Taylor *et al.* 2021). A change of mindset from decision-makers and urban dwellers with a carbon-intensive lifestyle could be the most difficult part; the attitudes of the majority, as the COVID crisis has shown, can change quickly, but also could revert back to 'normal' at the end of the sanitary crisis.

Claims of a new era for the promotion of a healthier, more inclusive, and more sustainable city are not new. Often after major political changes, like the end of apartheid in South Africa, attempts have been made to encourage the inclusion of the poor and to recognise their capacity for self-organisation, but authorities have after a while reverted to the habit of recognising only organised and regulated space (Muray 2008: 140–53). Neoliberalism in its different forms around the world by consecrating the role of private developers, and by emphasising good governance with only few stakeholders and excluding the voices of the majority, makes the dream of a healthier sustainable city impossible (Myers 2005: 139–43, Cash 2016). It may be one of the lessons of COVID-19 that strong public intervention and regulation are needed, but can work in a complex world only with the effective democratic participation of everyone—and the creation of commons network governance approaches seem preferable to a strong interventionist state (Oosterveer 2009). Their theorisation should be systematically explored in Africa, as in the rest of the world, as networks of decentralised infrastructure and multilayered governance of political territories combined with the self-organisation of communities may defuse tensions and conflicts; this could help cities to be more resilient and adapt to climate change (Simone 2010, Leal Fihlo *et al.* 2018). But this will have to reverse a long history of urban planning in Africa which from colonial settlements until today has been built on deliberately pushing aside the majority of urban dwellers into the invisibility of the informal world.

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'We need ground space': urban densification and transitional housing in Ethiopia

Minna Sunikka-Blank, Dawod Abdie and Ronita Bardhan

Abstract: Like many countries of rapid urbanisation, Ethiopia has an acute low-income housing shortage. Ethiopia's Integrated Housing Development Programme (IHDP) can be seen as an attempt to innovate low-income housing provision. Over 200,000 IHDP units have been built since 2005. Drawing from a Post Occupancy Evaluation (POE) survey in Amhara region, this article asks how the transition to high-rise has affected household practices and energy use. The POE survey shows low satisfaction among the residents, despite energy access and sanitary facilities. The new built environment compromises and contradicts established cultural practices, reducing the residents' well-being compared to previous living in more informal settlements where the dwelling had direct access to outdoor space and community. This means that the residents tend to view IHDP housing as transitional, disincentivising improvements in the environment or social networks. Further, the loss of ground connection causes domestic and cultural practices to move indoors, increasing energy demand and reliance on appliances. This paper argues that high-rise as the only typology for mass housing should not go unchallenged. If it is the only option, design standards should not be left open to interpretation by the developer and regulations should ensure adequate design, such as dual aspect, flexibility and privacy in floor plans, and design and designation of outdoor spaces. The findings question the idea of modernisation of housing as a linear process and challenge the literature on the compact city model as 'the' paradigm for sustainable cities in Southern urban practice.

Keywords: Low-income settlements, slum rehabilitation, domestic energy, urban densification, housing policy.

Notes on the authors: see end of article.

1 Introduction and context of study

According to the UN, 90 per cent of urbanisation will take place in the developing world in the coming decades. It is estimated that two billion people will live in slums. Providing low-income housing and energy access, in the context of rapid urbanisation, densification of low-income settlements, and climate change, is an urgent challenge for cities. Presently, informal settlements form a significant part of the urbanscape in Addis Ababa with more than 70 per cent of the city's population residing in them (Ozlu *et al.* 2015). In Mumbai, the figure is 40 per cent (Bardhan *et al.* 2015a). Mumbai's Slum Rehabilitation Authority (SRA) housing scheme and Ethiopia's Integrated Housing Development Programme (IHDP) can be seen as attempts to innovate low-income housing provision and increase urban density. SRA and IHDP housing are successful in many respects. They provide sanitary facilities for households who previously did not have them and offer energy access with cleaner fuel supplies such as LPG (liquefied petroleum gas) or electricity. SRA and IHDP sites can be seen as 'places of becoming' for the emerging urban middle-class and they have turned many low-income households, who are lucky enough to get them, into landlords. In Addis Ababa, an IHDP condominium unit on inner-city land can sell for up to 1.5 million birr (US$72,000) (Goodfellow 2017).

Programs like SRA and IHDP are designed to maximise the number of housing units to be built on a given piece of land. SRA, for example, is financed by offering builders incentives to create high-density developments of high-rise flats. A family apartment is only 24 m^2 and often home to six or seven people. Since 1995, the SRA, has completed over 200,000 rehabilitation units in Greater Mumbai. In Ethiopia, 200,000 IHDP units have been built since the start of the programme in 2006. Despite the high construction volumes, current studies on the IHDP (Adamu 2012, Eskedar 2012, Planel & Bridonneau 2017), or the exceptionally rapid urbanisation rate in Ethiopia (Keller & Mukudi-Omwami 2017, Alemayehu *et al.* 2018, Larsen *et al.* 2019), have not addressed the question of energy demand. On the other hand, studies on domestic electricity demand in Ethiopia (see Guta *et al.* 2015, Kebede *et al.* 2018, Mondal *et al.* 2018) seem to take the drastically rising demand for granted.

The authors' previous research assessed women's experiences and energy use in four SRA housing colonies in Mumbai (Mankhurd, Natwar Parekh Colony, Sangharsh Nagar Housing, and PMG Colony) and contrasted it with the housing policy objectives. The study was part of the British Academy Knowledge Frontiers Scheme in 2017/2018 and the findings were reported in Sunikka-Blank *et al.* (2019) and Bardhan *et al.* (2019). The SRA housing scheme has been seen as one example for the IHDP. After visiting IHDP projects in Ethiopia in 2019, the authors wanted to compare the outcomes of the SRA and IHDP housing schemes. In SRA, we had observed a link between the building typology, women's household practices, and energy use (see Sunikka-Blank *et al.* 2019). The connection between the built form and energy use has also been discussed by Nutkiewicz *et al.* (2018), Debnath *et al.* (2019a), and Malik *et al.* (2020). Research on everyday practices in shaping household energy demand is well established in Western energy studies (see, e.g., Røpke *et al.* 2008: 595–611, Gram-Hanssen 2010, 2014, Shove & Walker 2014), but very few studies have applied it in the context of countries in the Global South (e.g., Wilhite 2008, Sahakian 2014, Smits 2015, Browne 2016, Khalid & Sunikka-Blank 2017, 2018), yet practices of energy consumption are often very different in poorer countries (Roy 2000). Each country has its own unique, socially and materially structured set of interlinking ideologies, cultural norms, and pace of progress that shape the continuity and change of practices within the society (Abdul-Qadeer 2006). This research is guided by Shove (2010, 2014) who looks at energy practices as a social construct rather than as rational behaviour: energy studies tend to see users' behaviour as 'irrational' but without acknowledging that, if technical solutions (including housing, energy infrastructure, and domestic technology) go against everyday life and practices, they will not be adopted or will have unintended consequences.

Ethiopia is an interesting case study as it is the second most populous country in the African continent and it is growing rapidly— the annual growth rate averages at 3.5 per cent. The World Bank is expecting the Ethiopian urban population to triple to that in 2020. Ethiopia's urban population is estimated to be 23 per cent. By 2028, 30 per cent of the population is likely to live in urban areas. Housing to accommodate them has yet to be built.

Before assessing Ethiopia's mass housing scheme (IHDP), it is important to understand the context of the study. In the 19th century, the process of expansion and centralisation in Ethiopia led to the establishment of towns (*Ketemas*) across the country, mostly for military and religious purposes (Ambaye 2011, Terfa *et al.* 2019). In the early 20th century, new types of towns emerged along the main transport routes. Landowners were free to construct *chika* houses (houses built by traditional methods with wood, mud, and straw), often without formal planning permission, whereas permission was required for more permanent houses. During the period 1974–91, all rural and urban land rental structures were nationalised and the *kebele* structure was put into place, *kebele* being the lowest administrative unit in Ethiopian towns. Under the communist *Derg* regime, 60 per cent of housing in Addis Ababa was rental accommodation and state-owned *kebele* housing, usually built with local wood and mud walls, accounted for 93 per cent of the rental sector. Today a lot of *kebele* housing is outdated and in poor condition, without adequate sanitary facilities.

Access to housing for poor-income households is one key point of the Ethiopian Housing Policy (Ministry of Urban Development and Housing 2016), which is implemented by government-led programmes and cooperative housing schemes. Affordable housing schemes are supported through free land supply, taxation, technical support, established saving schemes, loan arrangements, and capacity building models. The Integrated Housing Development Programme (IHDP) is a purely government-led and financed housing provision programme for low-income and middle-income households that was launched in 2004 (1996 in the Ethiopian calendar) by State Minister Oqubay Arkebe. Within the IHDP, specific projects are undertaken on either brownfield sites or in slum areas that are cleared and the residents rehoused. Urban densification is one driving concept behind the programme and a condominium housing typology has been adopted. There are four main IHDP apartment typologies: studio, and one-bedroom, two-bedroom, and three-bedroom flats. The lowest income families can only afford the smallest units, leading to overcrowding and poor living conditions. Households who have large family sizes, or are newly married, tend to rent out their IHDP tenement and go back to informal settlements where they have more space. It has been estimated that more than 90 per cent of IHDP studio flats are occupied by renters (UN-Habitat 2011).

This research focused on Amhara region. We wanted to look beyond the capital city as studies on IHDP have been limited to Addis Ababa, where IHDP sites are located in urban peripheries, due to lower land costs and land availability, creating a set of problems from the outset that are related to commuting, and lack of facilities and local employment. In secondary cities like Bahir Dar, low-income housing can be arranged more polycentrically, encouraging smaller *in situ* compounds with reasonable density, access to jobs, schools, and other facilities, and shorter commuting distances.

Bahir Dar is the capital of Amhara region that has to meet the intense needs resulting from rapid urbanisation. Bahir Dar city has had two master plans, in 1965 and 1996, and an Integrated Development Plan (IDP) in 2006. The IDP was followed by a new Structure Plan (SP) in 2020. The main drivers behind the new SP are: the allotted land or the parcel area of the land-use types assigned in the previous plan are insufficient for the intended urban function; the shape of land use is unsuitable; modalities for affordable housing provision are inappropriate; and there are problems in building height and in regulating density. The Bahir Dar SP goals are linked to the UN Sustainable Development Goals (SDG), the New Urban Agenda (NUA), the Ethiopian National Urban Development Spatial Plan (NUDSP), and the Second Growth and Transformation Plan of Ethiopia (GTPII). ‘Compactness’ and ‘inclusiveness’ are core values in Bahir Dar SP, translated to Key Goals 1 (Compact Eco City), 6 (Social Inclusion and Urban Safety), and 7 (Affordable Housing).

Bahir Dar has around 176,600 households and an average household size is 3.3. ‘Very poor’ households make up 20.8 per cent of this figure, ‘poor’ 19.3 per cent, 'middle' 20.3 per cent, and 'high income' 19.6 per cent. The current housing deficit is estimated to be around 82,000 units. This means that more than 270,000 residents are in need of adequate shelter. As part of the national Integrated Housing Development Program (IHDP), Bahir Dar Integrated Housing Development started building IHDP condominiums in 2007. The main responsible party for IHDP developments is the City Administration Housing Development Agency. There is an increasing tension in creating new high-density housing developments and land provision. One problem is the size and shape of parcel land plots for large-scale housing projects. Small plots of 105 m^2 (7 m × 15 m) are most common in the inner city and they are inefficient for densification. Yet over 2,000 IHDP units have been built in Bahir Dar alone, half of them allocated to governmental workers.

Drawing from a Post Occupancy Evaluation (POE) of IHDP projects in Amhara region in Ethiopia, this article looks at household practices and energy demand in low-income housing. It asks: What are the (un)intended consequences from transition to high-rise? What is the residents' lived experience in IHDP projects and how has the housing transition affected household practices and energy use?

The paper is structured as follows. Section 2 presents a literature review of urban densification in the context of low-income settlements. Section 3 describes the methodology. The findings of the POE survey in Amhara are presented in Section 4. Section 5 offers a comparative perspective between IHDP and SRA policy in Mumbai, India. Section 6 concludes.

2 Literature review

There are considerable benefits to community-led, incremental, and *in situ* slum upgrading. According to the United Nations—Habitat III, participatory slum upgradation is one of the most efficient ways of creating affordable housing for future slum urbanites, and using densification can fulfil the UN-SDG-11 of sustainable communities (Evans *et al.* 2016). Slum rehabilitation or upgradation projects have been taken up by many cities of the Global South as a solution for slum-free cities. In Africa, 41 out of 54 countries have announced large affordable housing construction projects—known as slum-upgradation projects—led by state-owned development agencies (Collier & Venables 2017). However, the economic reality means that slum rehabilitation and low-income housing programmes will, inevitably, happen at scale. Urban densification is a key driver behind the IHDP. There is an ongoing debate between the 'compact city' and the 'sprawling city', or, more fundamentally, the 'compact city' and the 'sustainable city'. Urban densification is seen to be leading the debate. Yet with some exceptions (see, e.g., Nallathiga 2007, Bardhan *et al.* 2011, 2015a, 2015b) most studies have focused on Western contexts. Urban densification has been used as a strategy to develop sustainable future cities through the *compact city model.* Adopting the same in Global South city contexts comes with its own sets of implication. The core question—whether densifying already hyper-dense cities of the Global South can produce the desired effect—forms a significant part of sustainability scholarship. It is common sense to perceive that cities with high-density struggle to cope with rapid urbanisation and the associated negative externalities of congestion, contagion, and pollution. But higher population densities may not translate into well-being. Yet, research has demonstrated that densification in Global South cities can produce creative productivity and prosperity (see Bardhan *et al.* 2015b, Brown 2017, Kshetrimayum *et al.* 2020, Visagie & Turok 2020). A prominent characteristic of Southern cities is the concentration of population in informal settlements. Presently more than one billion people live in the slums of Global South cities, which by 2050 is projected to grow to more than three billion: that is, 30 per cent of the projected world population (UN-Habitat 2016). Hence, understanding the use of density for progress in informal housing needs special scrutiny when housing this massive slum population is an urgent item on the global agenda. An underlying assumption is that, by improving planning and increasing density in unruly cities, they will become more sustainable. Existing theories of urban real-estate investment are unable to explain developments in cities like Addis Ababa (see Goodfellow 2017, 2020). There is even less understanding of urban densification of low-income housing that responds to the lived reality and actual needs of residents.

The failure of a series of slum improvement programmes since Indian independence (1947) has led to a neoliberal model slum rehabilitation which relies on densification (Bardhan *et al.* 2015a). Similar projects have been adopted in Brazil, the social housing programme Minha Casa Minha Vida (My House, My Life; PMCPV); in Ethiopia, the Grand Addis Ababa Integrated Housing Development Program (GAAIHDP); in Indonesia, the Kampung Improvement Program (KIP) (see Harari & Wong 2019); and the urban villages of China (see Ren 2018). One common thread across these developments is that they are all built on the compact city model of intensifying property development by incentivising affordable housing.

Mumbai's slum rehabilitation has a development density of more than 50,000 persons per square kilometre, compared to 106,200 persons per square kilometre in PMCMV in Brazil and 61,333 persons per square kilometer in GAAIHDP in Ethiopia (Lamounier *et al.* 2019, World Bank 2019, Pardeshi *et al.* 2020). High densities are accommodated through upward expansion in the form of multistorey dwellings, thereby releasing considerable land for rapid urbanisation developments such as SRA housing. Although vertical development does not assure better living, it can reshape the built environment by liberating ground space for alternative uses. This can provide mixed land uses, including retail and housing, which is a factor in the compact city model, the ultimate paradigm for sustainability (Bibri *et al.* 2020). While urban densification alone cannot meet the goals of the compact city model, it can be used as a proxy for the intensity of land use. Intensifying land use only offers the advantage of alleviating land resources to meet the infrastructure growth demand from rapid urbanisation, but it alone does not ascertain sustainability, especially in already hyper-dense cities of the developing world. Bardhan *et al.* (2015b) demonstrated that scaling the compact city model for realisable benefits in high-density cities of the Global South needs an integrated and contextualised approach. Solely depending on intensifying neighbourhoods can have detrimental effects on health and social sustainability (Bibri *et al.* 2020). Unlike the cities of the developed nations, the already high-density cities of the developing world have urbanised without the benefits of industrialisation and have historically witnessed organic planning. Such trajectories have led to self-organised sustainability within the hyper-dense environment. Studies on the relevance of the compact city model for high-density cities of the developing nations reinforce that, although the compact city model is achievable in these cities, most of it is operationalised through urban densification with little adherence to the attributes of the compact city model (Biderman *et al.* 2018, Nadeem *et al.* 2021). The critical fallacy in achieving sustainability through the compact city model is that economic sustainability stills remain intrinsically central to the model. This is also the rationale for high-density developments like GAAIHDP in Ethiopia or Slum Rehabilitation Housing in India. Hence what happens to health and well-being in such cosmetically induced density remains a question.

Though a common success attributed to upgradation projects is land tenure and legal rights to the city for poor urban dwellers, most of these houses are not more than 30 m^2 and must accommodate large households. Hence, the well-being effects of using densification for slum upgradation projects reveals varied results. China's 'urban villages' have been successful in producing a creative economy of local entrepreneurialism (Ren 2018), but there are mixed outcomes for India, Brazil, and Ethiopia. A series of studies conducted on the quality of life in Mumbai's rehabilitation houses shows that, while inhabitants are generally satisfied with tenured housing, the knock-on effects of high density and poor housing design have led to severe consequences on public health, skewed energy justice, gender discrimination, and the breakdown of social networks (Bardhan *et al.* 2019, Sunikka-Blank *et al.* 2019, Pardeshi *et al.* 2020). A major criticism of the PMCMV in Brazil is the spatial and social segregation that these houses create because of their location in the outlying suburbs of large urban areas. Locational disadvantages like these result in reduced mobility and accessibility to primary urban utilities like job markets, schools, and health and social services. The PMCMV is also seen to have low minimum standards in housing design (see Kowaltowski *et al.* 2015). Ethiopia's IHDP has been hailed as a success because of its pragmatism in solving urban housing crises and subsequently generating 737,256 job opportunities (Bah *et al.* 2018). However, there is a knowledge gap of the lived experience and energy use in IHDP housing, especially beyond the capital Addis Ababa.'

3 Methodology

The research is based on a Post-Occupancy Evaluation (POE) survey of 67 households who live in IHDP housing sites in Amhara. The survey questions asked about the occupants' satisfaction in IHDP, in comparison to their previous settlement. The survey was set up and conducted by researchers at Bahir Dar University. Two types of IHDP condominium sites were mapped in the POE survey. Six sites were selected from three main cities in Amhara, two from each city: Yetebaberut (*kebele* 16) and Bemesigid in Bahir Dar (*kebele* 14) (as seen in Figure 1), Hawariarw and Pawlos in Gondar, and Mekanyesus 1 and Mekanyesus 2 in Dessie. The same overall design strategy has been implemented all six IHDP sites that were surveyed, with very minor modifications. The first-stage IHDP projects tend to have communal buildings (for example, Yetebaberut) whereas the later ones do not (for example, Bemesgid).

The IHDP building volumes can be categorised as T-blocks, L-blocks, and linear blocks. In linear blocks the stair is external to the frame. In T-blocks and L-blocks, the stair is at the junction of the wings and there is a lobby-like space connected to the landings. In most IHDP blocks the number of housing units ranges from six to twelve. In most plan layouts the kitchen and the toilet are located next to the main circulation corridor. In later project sites the typologies have improved room arrangements. Figure 2 shows how the T-type block flats have three directional views and a more generous corridor space due to its views and each household's personal corridor space.

26 per cent of the POE survey respondents had one or two family members in their household, 27 per cent had a family size of three or four, 26 per cent a family size of five or six, and the rest had more than six members in the household. Compared to SRA where the average household size in a 25 m^2 tenement was 5.5, there is clearly less overcrowding in IHDP in Amhara.

14 per cent of the respondents in the POE survey had an income of less than 2,500 birr (US$76) per month, 19 per cent of the respondents had an income of 2,500–4,000 birr per month ($76–122), 19 per cent of the respondents from 4,000–5,000 ($122–152) birr per month, and the remaining households earned more than 5,000 birr ($152) per month. An average salary in Ethiopia is typically around 8,900 ($270) birr

Figure 1. IHDP site in Bahir Dar (source: the authors).

Figure 2. Linear-type IHDP block (left) and T-type block (right) (source: the authors).

per month, so most of the respondents were well below the average salary. In comparison, the average monthly income in India is 32,200 INR ($423) and in Mumbai 36,900 ($485), the average monthly income in SRA being 10,000 INR ($132).

IHDP housing modalities include 10/90 and 20/80 models where the beneficiaries have to save 10 per cent, 20 per cent, or 40 per cent of the total housing cost. The housing typologies are G+2 for 10/90, G+4, and G+7 for 20/8.

30 per cent of the POE survey respondents lived in studio flats, 30 per cent in one-bedroom flats, 33 per cent in two-bedroom flats, and the rest in three-bedroom housing units. 40 per cent of the respondents lived on the ground floor, 19 per cent on the first floor, 7 per cent on the second floor, 24 per cent on the third floor, and the rest in buildings which had more than four floors. More than half (60 per cent) of the respondents had lived in their flat for more than three years and only 6 per cent of them had lived in their flat for less than a year.

In addition to the survey in the Amhara region, we visited IHDP sites in Addis Ababa, such as the newly built Tulu Dimtu site on the outskirts of the city and the more established Jomo 1 and Jomo 2 in the inner-city area where property prices are already higher. The site observations included transect walks, and photography and filming on site.

The survey was limited to 67 responses. The small sample size is acknowledged as a limitation of the study, but this data is very challenging to collect and to the authors' knowledge, it has not been gathered from Amhara region previously. In order to discuss the applicability of the findings beyond Ethiopia, the survey results are compared to the SRA scheme in Mumbai in Section 6. However, the aim of the paper is not to generalise the findings but to contribute to the emerging discussion on practices and energy use in mass housing, in the context of urban densification in low-income settlements.

4 Results

According to the POE survey, residents find it challenging to adjust to life in high-rise buildings and the new locations of the IHDP sites. Table 1 shows the respondents' perception of 'comfort' in their current and previous housing modalities. In Bahir Dar, 90 per cent of the respondents said their previous house was more comfortable compared to the new IHDP condominium; in Gondar the figure was 63 per cent and in Dessie 52 per cent. Table 2 shows the households' perceptions of characteristics that they perceived as positive in their previous homes ('social life') and in their new condominiums ('freedom', this translating as them owning their property). Childcare was seen to be more positive in their previous location in all sites apart from Dessie.

Table 1. Respondents' perception of 'comfort' of their housing modality before and after the transition to IHDP (in percentages).

	Bahir Dar		*Gondar*		*Dessie*			
	before	after	before	after	before	after	before	after
Comfort	90	10	63	37	52	48	64	36

Table 2. Respondents' perception of positive characteristics of their home before and after the transition to IHDP (in percentages).

	Bahir Dar		*Gondar*		*Dessie*		*In total*	
	before	after	before	after	before	after	before	after
Social life	50	0	6	0	21	14	21	7
Freedom	0	100	63	100	36	50	38	75
Outdoor space and activities	20	0	6	0	15	7	13	4
Childcare	30	0	25	0	29	29	28	14

The main reasons for the dissatisfaction with the new IHDP housing were: living in a flat, loss of ground access, and difficulties in performing cultural practices in the new environment. The traditional, vernacular dwelling unit in Amhara is based on a circular, single room, built with local materials. In traditional housing the outdoor space is used for similar practices to the indoor space. Baking traditional food like bread (*injera*), washing and drying clothes, grinding seeds and coffee, drying ingredients for cooking, and the related social and daily activities are performed outside, on the ground. Also living and working are strongly connected with being outdoors. Further, the physical layout of traditional Ethiopian home requires defined spaces for domestic practices, such as cooking, to be performed close to the 'wives' quarters', and private rooms (for example, the toilet) to be located far away from more public spaces in the house.

The survey shows that 11 per cent of the respondents had modified their IHDP condominium and 89 per cent had not. 90 per cent of the respondents said they would like to modify their housing unit if they could. For those who had modified their unit, the need for privacy was the main reason. In linear IHDP blocks, toilets are located next to the living room which is strongly disliked by the residents. Some residents in the Hawariaw Pawlos site in Gondar had changed the location of the toilet to the balcony side at the back of the flat and installed an external PVC riser. Bathing practices have the highest level of privacy in Ethiopian culture and the residents would prefer the toilet and washing space to be accessed via the entrance hall and located at the back of the flat. Other reported modifications were changes in the positions of the internal doors, steel frames added to balconies to make them part of the interior (used as storage or an extra room), and the use of the external corridor space for children to play in, and installing a gate to protect the connection to the staircase.

Common circulation spaces (outdoor corridors, landings) were widely used as social spaces. For example, when indoor living space is not sufficient to accommodate neighbours and participants for a coffee ceremony, residents performed it in the outdoor corridor. The corridors are also used for cooking and grinding spices and, during electricity power cuts, they act as resilient space where residents can cook with wood or charcoal. 70 per cent of the respondents said the corridors are not wide enough.

Our previous research in SRA housing in Mumbai suggests that: a) transition to a more permanent home aligns with an increase in energy demand, either by necessity (for example, lights and fans) or convenience (digitalisation of social practices) (Debnath 2019a, 2019b); and b) high energy costs are a key factor in the 'rebound' effect when households have to move back to slums when they cannot keep up the monthly maintenance and energy payments (see Debnath *et al.* 2019a, 2019b, Sunikka-Blank *et al.* 2019). Figure 3 shows the energy source used for cooking in the surveyed IHDP housing, compared to previous housing modalities: 71 per cent of the survey respondents used wood and coal for cooking in their previous homes (29 per cent used electricity), but after moving to their condominium 96 per cent of the respondents only use electricity and only 4 per cent use wood or coal. Some reported liking smoke from using firewood, believing that fires, smoke, and burning incense are important aspects of the customary way of life which can be lost in the new condominium environment. Cooking practices have changed due to access to electricity. Traditional *injera* bread-making and coffee grinding are done more often with appliances after the housing transition. Table 3 shows that, in the previous housing modalities, 50 per cent of the respondents ground coffee manually, 26 per cent did it using an electronic appliance, and 24 per cent used both methods. After the transition, 83 per cent of the residents use an electric appliance to grind coffee, only 3 per cent do it manually with a pestle, and 14 per cent use both. It should be noted that coffee grinding is important in Ethiopian culture—the residents reported they want to smell the coffee when it is roasted and hear when coffee beans are ground.

Table 3. Coffee grinding practices before and after the transition (in percentages).

	Bahir Dar		*Gondar*		*Dessie*		*In total*	
	before	after	before	after	before	after	before	after
Manually with pestle	69	0	40	5	43	0	50	3
Using electric appliance	6	87	35	79	36	86	26	83
Both	25	13	25	16	21	14	24	14

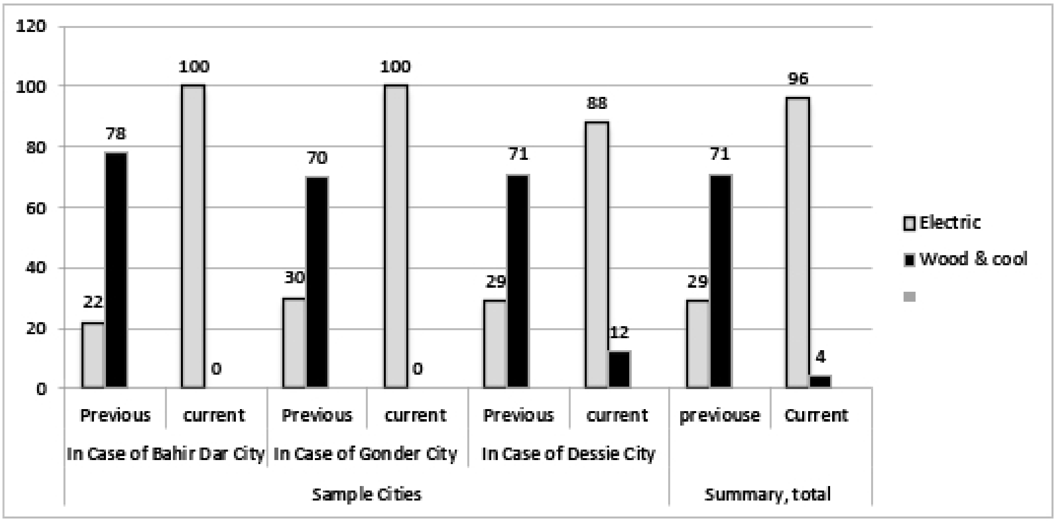

Figure 3. Energy source used for cooking in IHDP, compared to the energy source used in the previous housing modality (in percentages).

One main reason for dissatisfaction with shortcomings is the perception of IHDP sites as an unsafe environment for children, and also in smaller towns in Amhara. Yet Lappi and Gezahegn (2018) have reported that the decision to move into IHDP housing is often seen as future investment for the children, even if the transition was incompatible with the family's current lifestyle and income. The reason why IHDP sites are seen unsuitable for children is the poor quality of the open space and how it is used. 52 per cent of the respondents described the semi-public space between the buildings as 'bad'. Only 4 per cent of the respondents saw the open space as 'very good' and nobody described it as 'excellent'. By contrast, 71 per cent of the respondents described the open space in their previous housing as 'good' and 18 per cent as 'excellent'. In previous housing, children could play outside in communal pockets where women could keep an eye on them while sitting outside and interacting with their neighbours, but in IHDP condominiums children are not necessarily encouraged to play outside due to lack of safety and security. Further reasons for dissatisfaction with the open space was unallocated use (which means it is used for parking) or the housing committee using the common space for their own income generation. Some housing committes have added a guard house and a security fence to the compound and have a guard on site, paid for by the residents. Female respondents have also reported that IHDP sites have no space allocation for washing clothes and putting them out to dry (Pankhurst & Tiumelissan 2013). Those IHDP sites that do not have communal buildings use the open space for slaughtering goats and sheep. Animal slaughtering is an important cultural practice and social bond in the community.

In IHDP sites, slaughtering practices often have to take place off-site: in Bahir Dar 69 per cent of the respondents said they participate in animal slaughtering on site, compared to 85 per cent in their previous location. Further, as shown in Figure 4, only 31 per cent of the respondents prepared traditional drinks in new condominiums, compared to 61 per cent that were able to do so in their previous homes.

In those sites which were implemented in the first phase of the IHDP, there is usually a two-storey communal building on site, accommodating a communal kitchen or a laundry. In some cases they were seen obsolete by the respondents: one interviewee said that, as every household uses electric appliances for preparing *injera* bread inside their unit, they only use the communal building for occasional ceremonial activities. In areas of higher demand like Yetebaberut in Bahir Dar, the communal buildings have been rented out. The housing association, who decides on the use of communal buildings and open space, consists of the board representatives, elected among the residents. Every unit owner becomes a member of the association. The association enforces by-laws, manages maintenance and repair issues, and deals with any disputes between the unit owners. The housing associations can use communal buildings for income generation and rent them as shops, laundries, residences, or beauty salons. In the POE survey, the respondents expressed a preference for maximising the communal spaces in the main housing blocks rather than having separate communal buildings.

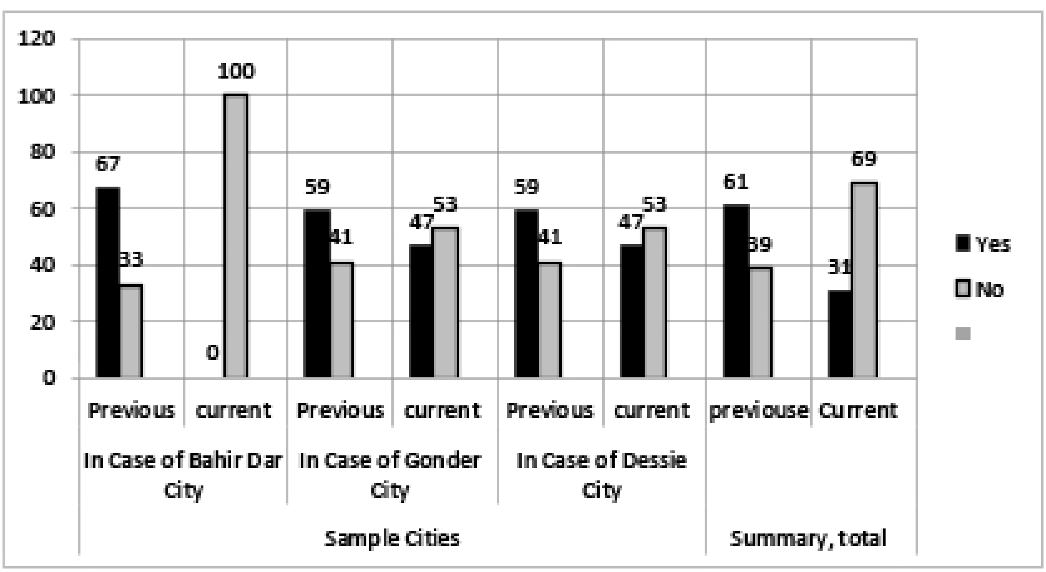

Figure 4. Traditional drink preparation in IHDP condominium in comparison to the previous housing modality (in percentages).

The social networks among the IHDP residents are weak compared to their previous communities—even if 90 per cent of the respondents said they still participate in typically Ethiopian social cooperation and associations such as '*Idir*' (a social insurance association that provides economic support for its members in case of accident, death, or damage to property) and '*Ikube/Iqub*' (a traditional means of saving outside the formal financial system where *Iqub* members make regular contributions to a pot that is distributed on a rotating basis). Residents of one block said they occasionally come together in cultural ceremonies, but any socialising with the residents in the next block is rare. A high number of IHDP residents are tenants and overall there is a high turnover rate because of the constantly increasing rent value of the apartments, even in Amhara region. The residents' perception of their IHDP sites has changed over time, as observed in the survey:

> *At the time the condominium buildings finished and transferred to the beneficiaries the people fears to live in but after some time the residents changed the perception on condominium housing and there is also some cultural modification now days residents especially tenants prefer and want to live in condominium housing* … .

Consequently, the IHDP condominiums are seen as transitional rather than permanent homes. This is partly due to high prices for smaller floor areas that encourage larger families to move out, inflexible and standardised building design, and the loss of ground space, which transforms cultural and domestic practices and draws them indoors and to the private realm. If residents cannot modify their housing to meet their actual needs, then they tend to view new condominiums as transitional:

> *I don't feel it like 'safer' rather I feel it like transitional type of house. Because even though we are the owner of the house we always dream to have plot type housing. We need ground space so if our income increases we will sell these house and we will buy detached housing type which has ground space*.

5 Discussion: comparative perspective

The slum rehabilitation programme in Mumbai, led by the Slum Rehabilitation Authority (SRA), was one model for IHDP. Table 4 compares IHDP and SRA schemes in terms of management, finance, allocation, landownership, design, construction and maintenance, and energy infrastructure.

Both IHDP and SRA aim to solve low-income housing crises but by very different means. IHDP has a strong lead from the state, but SRA policy is implemented through market-led mechanisms and built by commercial developers. SRA aims to incentivise the private sector to participate in slum redevelopment. In principle, this model is

Table 4. IHDP scheme in comparison to slum rehabilitation housing (SRA) policy in Mumbai, India.

	IHDP (Ethiopia)	*SRA (Mumbai, India)*
Lead	Government-led (since 2005). Aim: 400,000 new units and 200,000 jobs. 200,000 built in Ethiopia, housing shortage still estimated to be 1million in urban areas.	Developer-led (since 1990). Aim: To make slum-free city and provide housing tenure to urban slum dwellers.
Finance and allocation	Government funded. Waiting list, computer-based lottery (30% tenements allocated to women), down-payment (10–30% of the value) and mortgage. Construction cost of a unit estimated at 154 US$/$m^2$, 1-bedroom selling price 900 US$/$m^2$ (in 2007), 2-bedroom selling price US$1,300–2,000. Rental income higher than mortgage payments, turning low-income households into landlords (up to 70% units rented out).	No capital costs for the urban slum dwellers who need to qualify with a slum card and agree with the developer (mixed or *in situ* developments). The tenement is provided free of cost to a verified and registered slum dweller. No published information on construction costs. High number of SRA units rented out.
Landownership	Built on government-owned land, later the homeowners own the land together. Need to densify valuable inner-city land.	The land belongs to the government. There are special building by-laws specified by the Slum Rehabilitation Authority for building these housing units.
Design	'MH Engineering' manual sets the basic design standards, little variation and flats from studios to three-room flats, smaller units subsidised all based on standard plans. Usually 4–5 storeys high, 175–300 households/hectare, very large plots mostly in urban peripheries. Ground floors reserved for livelihoods, shops, cafes, etc.	Special planning guidelines for Slum Rehabilitation projects. *In situ* or through TDR (transferrable development rights). Different building typologies (8–10 storeys), each unit should be at least 22.5 m^2 with a toilet facility either within the unit or at a common place within the same floor.
Construction	Concrete frame, both pre-cast and *in situ*, masonry infill walls, single glazing. Government controls the Ethiopian construction industry, but there is large informal building sector.	Concrete frame, masonry infill walls, single glazing. Private contractors are liable to construct the houses following the special planning regulations for the Slum Redevelopment Authority.

Table 4. *Cont.*

	IHDP (Ethiopia)	*SRA (Mumbai, India)*
Management	Condominium Association and elected Board of Directors, management of open spaces, security and communal buildings, rubbish door-to-door collection.	Slum rehabilitation housing is managed overall by the government's special purpose vehicle Slum Rehabilitation Authority. Each building within the Slum Rehabilitation housing has a Management Corporation.
Energy infrastructure	Electricity grid, but it can be unreliable, power cuts.	Electricity and LPG access, measured use (seen as inaccurate and irregular by the occupants) and billing.

marketed to create a win–win scenario for all parties: the government, the private sector, and the slum dweller. Slum dwellers get housing ownership at zero cost; the government gets the land occupied by slums as a a resource to subsidise housing for the urban poor, while effectively tackling the problem of land shortage and reducing housing deficits. The private sector benefits from free access to prime city land, with few obligations in the redevelopment process. IHDP, on the contrary, is governed by public bodies who are therefore in a very strong position to set minimum standards and maintain medium density. Yet, due to a deposit and mortgage payments IHDP housing is unaffordable for many—even if they are lucky enough to win the allocation lottery.

The IHDP programme faces specific affordability challenges in terms of gender. While special provision for female-headed households is being addressed through the mandatory 30 per cent allocation quota for female-led households, the reality is that many of the poorest households who cannot afford any size of condominium housing are female-headed. Many are single mothers with little formal education and no employment. These women and their children are therefore excluded from the development plans. Apart from some initiatives led by NGOs (non-governmental organisations) (for example, the Lideta case study for 200 women), there are no policies, public systems, or financial support to facilitate women's access to IHDP housing. There is also no consideration of the needs of aging residents or residents with disabilities, in design or allocation. Residents with phyical or mental disabilities struggle to access condominium housing units in housing blocks in the upper floors, forcing them to permanently assign a family member to look after them (Petros 2016). In SRA, allotment is based on the head of the household who is a legal tenement of the notified slums, irrespective of gender.

The data we had previously collected from four SRA case studies showed that, due to poor design in three out of four SRA housing typologies, comfort practices had become reliant on electric appliances like fans and air-conditioning units. A survey of

1,224 households at SRA colonies in Mumbai showed that higher appliance ownership in the new slum rehabilitation housing was due to changes in household practices, the built environment, and affordability criteria of the appliances (Debnath *et al.* 2019a, 2019b). In slums, most households had paid an average INR 100 (≈US$1.5) per metered electricity connection, with an average of three or four connections per household. Electricity bills that used to be around 400 rupees (≈ $6) per month in the slums, in SRA went up to 1,000 rupees (≈$14.5) per month, on average. Increased maintenance and energy costs in SRA had pushed most households into energy poverty, whereby they spend more than 10 per cent of their disposable income on electricity and cooking fuel (reported in Sunikka-Blank *et al.* 2019). These themes have not yet been studied in such a detail in IHDP, but the POE survey indicates that practices are already becoming more reliant on appliances.

A comparison of thermal comfort and indoor air quality between the slums and SRA houses has in many instances shown slums to perform better (Lueker *et al.* 2020, Malik *et al.* 2020, Sarkar & Bardhan 2020a, 2020b). A satisfaction survey in SRA shows that more than 70 per cent of tenements are satisfied with the slum rehabilitation housing (Kshetrimayum *et al.* 2020). Yet living in SRA is associated with respiratory health burdens from diseases like tuberculosis (Bardhan *et al.* 2018, Pardeshi *et al.* 2020). All these studies have demonstrated that the poor performance accrording to energy use and health-related factors are primarily owing to the dysfunctional neighbourhood design of the SRA buildings and missed opportunity in understanding the socio-cultural context of the inhabitants. This generates a vicious cycle of poverty recycling by increasing the economic burdens from additional energy usage for achieving comfort or for seeking healthcare, which were absent in slum living. Much of the affordability issues in SRA arises from the additional energy costs and health-related expenditure, which are unforeseeable when the tenements agree to the transition. This leads to the costs of the free SRA housing outweighing its benefits. Such deficiencies in realising the latent costs of transition housing are yet to be recognised in literature or policy. In neoliberal literature, where affordable housing is considered to be less of a state subject and more driven by market speculation, mostly due to the failure of past state-led development strategies, NGOs play a critical role (Nijman 2008). The NGOs contribute to the differential citizenship by mediating the expectations of the transitional housing dweller to the government. In SRA, such mediation is transacted through hierarchical levels of cooperative systems formed by the tenements, act as mediators. However, the lack of similarity in the vocabulary of expectations between the residents and the policymakers acts as a barrier in achieving the desired welfare (Bardhan *et al.* 2019).

It became evident during this study, which started as a straightforward comparison, that the contexts in Mumbai and Addis Ababa, or in Bahir Dar, are very different.

We need to situate the findings in the context of rural–urban transformation and where the residents have come from. In SRA, households must already have lived in the city for ten years and possess a slum card in order to get an SRA housing unit, so they are already urbanised. Ethiopian cities have rapid rural–urban migration with residents who only recently may have lived in traditional housing. However, the research findings do question the ideas of modernisation of housing as a linear process, as acknowledged in the postcolonial discourse, that criticises seeing stakeholders as subjects of obligation and experts imposing on them 'the will to improve' (Murray Li 2007). Any in intra-urban comparisons, even between similar housing typologies, need to be carefully considered. However, the findings suggest a number of policy implications that are relevant beyond the Ethiopian context. These are discussed in the next section.

6 Concluding remarks and policy implications

First, the study challenges the existing literature on the compact city model as 'the' paradigm for sustainable cities in Southern urban practice and in secondary cities. The POE survey shows low satisfaction in new condominium housing, despite technically improved living conditions, and access to the energy grid and sanitary facilities. The new environment compromises and contradicts established cultural practices. This reduces the residents' well-being compared to previous living in more informal settlements where the dwelling had direct access to outdoor space and community. Therefore, the residents tend to view IHDP housing as transitional, leaving little incentive to improve the environment. This paper argues that high-rise as the main typology for low-income settlements should not go unchallenged. Courtyard housing and 1–2-storey high buildings, with ground access, should be prioritised, especially in secondary cities where land prices are not as high as in capital cities.

Second, the loss of ground connection in IHDP housing means that most domestic practices (cooking, cleaning, childrearing, entertainment) and cultural performances (here the coffee ceremony) move from outdoors to indoors, increasing reliance on electric lights, fans, and appliances. This study confirms findings from the previous literature (Sunikka-Blank *et al.* 2019, Debnath *et al.* 2019a, 2019b) that poorly designed mass housing reinforces the distributive energy injustice if poor households are locked in unsustainable housing where they are dependant on energy use they cannot afford. Energy demand could be mitigated, from the outset, in housing policy. In Ethiopia, the Ministry of Urban Development and Housing (2016) has assigned the 'Urban Housing Policy and Strategy' to bridge the gap in housing shortage but, while the Housing Policy briefly refers to 'the environment', domestic energy demand is not even mentioned.

Third, when low-rise or medium-rise housing is unfeasible, prescriptive design standards for high-rise buildings should be set. Standards for low-rise or self-build are less urgent, but in high-rise the implications of poor design are drastic. For example, in order to ensure sufficient daylight and cross-ventilation conditions, each unit should have openings to more than one direction. Floor plans should be designed to be flexible and private, supported by a wide outdoor circulation spaces and extended landings. Open green spaces need to be designed and designated for specific purposes, including the needs of women and children (play areas, laundry and drying clothes) and cultural ceremonies (here animal slaughtering and coffee ceremonies). If a mass housing programme is led by the state, rather than the market, it is more straightforward to impose and enforce the design standards.

It is acknowledged that this procedure of placing the complete onus of development on the state has failed in the past owing to complex procedures in land transaction and compensation. Such failures had let slum policies take a neoliberal turn to become contingent on the market or NGOs (Nijman 2008). Transitional housing is an adaptation of neoliberalism with the state being an apex regulating body for compliance checks with the broad slum rehabilitation policy. As in less-developed countries, where neoliberalism has been successful in fundamentally altering development strategies, transitional housing policy can be considered as a productive strategy in the housing and poverty alleviation efforts of India and Ethiopia (Harvey 2005). However, the main difference in transitional housing in the developing world sprouts from the non-statutory nature of the policy. Apart from the maximum footprint of the tenement unit, the rest of the regulations are not obligatory. This causes inadequacies in achieving desired livability outcomes, as most of the requirements are open to interpretation by the developer.

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Developing climate-responsive cities: exploring the environmental role of interstitial spaces of Santiago de Chile

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Abstract: Drawing upon a range of writing on suburbanisation and urban sprawl, this paper outlines an approach to the analysis of interstitial spaces of urban sprawl. Such spaces are the outlying geography of metropolitan regions existing in-between developed or urbanised areas. As such, they constitute an eclectic mix of open spaces, natural areas, obsolete infrastructures, geographical restrictions, farming land, etc, that alternatively contribute to the city's environmental and functional performance. Despite being identified in the literature, there has been little recognition of interstitial spaces as part of the environmental sustainability of urban systems, and how they support cities in improving their resilience and adaptation capacities. Using the case of Santiago de Chile, this paper highlights an environmental approach to studying the interstices and the need to examine such spaces at different scales linked to their respective environmental potentials.

Keywords: Interstitial spaces, urban sprawl, climate change, urban sustainability, Santiago de Chile.

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Recent relevant publications:

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Introduction

Recent decades have witnessed debates within urban studies regarding the impacts of extended suburbanisation and what this implies for the nature of cities, the countryside, and the sustainability of entire regions (Keil 2017). These debates have been grounded in various conflicting theoretical approaches in which differing positions have been developed, including the ideological meanings of extended suburbanisation and sprawling growth (Phelps 2012). On the one hand, supporters of urban sprawl highlight the importance of extending suburbia as a way of tackling housing shortages whilst responding to increasing population and employment growth (Rice 2010). On the other hand, anti-sprawl narratives raise extensively documented issues of economic, social, and environmental impacts (Johnson 2001, Romero & Órdenes 2004). If we consider that nearly 80 per cent of global primary energy is consumed in cities and 60 per cent of the world's overall greenhouse emission is produced by cities (Gargiulo & Russo 2017), we would also need to clarify that this impact originates from extended suburbia as more than 85 per cent of urban dwellers reside in suburban areas (Keil 2017). In these contexts, spatial fragmentation and the extensive geographical scale of urban sprawl shape the city as 'no longer defined as an individualised centre nor does it correspond to a harmonious and coherent group of elements' (Sousa 2009: 61). Instead, the resulting sprawling geography is composed of a mix of built-up areas and a diverse spectrum of interstitial spaces that lie between developments that make cities physically discontinuous, spatially porous, and environmentally diverse.

These urban interstices, however, have not received enough attention in the planning literature—often focused on built-up space—even when they are intrinsic components of fragmented suburbanisation. Although calculated to be substantial (Dubeaux & Sabot 2018), the interstitial spaces are less examined due to their apparent condition as empty, undeveloped, under-developed, leftover, vacant, inert, or simply pending spaces for further urbanisation. Nothing could be further from the truth, however, as 'when one penetrates the system of interstitial spaces and starts to explore it, one realises that what has been called "empty" is not so empty after all. Instead, it contains a wide range of uses' (Sousa 2009: 66). Aside from their functional potentials, it has also been argued that interstitial spaces are the source of a substantial proportion of wealth that contributes to the organisation of society (Rickards *et al.* 2016, Zhang & Grydehøj 2020). It has been demonstrated that, 'despite a select group of urban centres generating a disproportionate amount of global economic output, significant attention is being devoted to the impact of urban-economic processes on interstitial spaces lying between metropolitan areas' (Harrison & Heley 2015: 1113). This also demonstrates the scalar significance of interstitial spaces—that ranges from the liminal space between two buildings up to the rural space between—while opening questions 'concerning how rural spaces are conceptualised, governed and represented' (1113). Interstitial spaces embrace both the 'rural' and the inner land of cities, including industrial areas, farming spaces, mining zones, natural reserves, landfill, brownfield sites, abandoned areas, conurbation spaces, desert land, mountains, rivers and large bodies of water, as well as other geographical restrictions with yet unexplored ecological contents (Gandy 2011). All of them constitute an interstitial geography that is often marginalised (and/or excluded) from studies of cities and their *built-up* dimension. This lack of attention becomes critical when raising questions around the environmental potential of interstitial spaces, how they contribute to the urban character of cities, and how they improve urban resilience under pressing issues of environmental pollution and climate change (French *et al.* 2019).

This article examines this environmental role of interstitial spaces in developing climate-responsive cities through combining morphological and qualitative analysis. The discussion is empirically based on the capital city of Chile—Santiago—from which three types of interstices are selected to analyse their spatial and environmental significance: a) a cluster of small-scale suburban farming lands, b) a large-scale cluster of mining sites surrounded by consolidated neighbourhoods, and c) the southern conurbation space defined by regional transport corridors linked to regional demands. The first case introduces the values of suburban rurality and open space in securing the social and environmental sustainability of deprived peripheries. The second case illustrates how a highly polluted mining site can become a valuable three-dimensional landscape that provides public space and stormwater collection within impervious suburbia. The third case unveils the potential of conurbation zones as hybrid spaces in which regional, urban, and rural systems enable adaptation strategies and climate-responsive peripheries. These interstitial spaces are multifaceted elements within the homogenous suburban space of Santiago, and present a clear potential of becoming valuable environmental assets for the whole metropolitan space. Located in the south of Santiago—the most important axis for suburban expansion—they are surrounded by large concentrations of social housing developments, regional infrastructure, agriculturally fertile land, and a system of microclimates that stabilise the metropolitan temperature and improve the city's resilience. However, these interstitial spaces fall into simplistic categorisations as 'empty sites' that can be further urbanised. These selected interstices are used as a basis for abstraction and generalisation, given that the analysis has salience to the vast majority of cities.

The research in which this paper is based involved mapping, semi-structured interviews, and spatial analysis of the selected interstices identified as strategic by policymakers. In the first section, debates on urban sprawl and interstitial spaces are expanded. This highlights the role of interstices in the suburbanisation process and their spatial significance from an environmental perspective. Then, the three selected cases from Santiago are described and analysed to provide insights into their environmental properties and how they can contribute to developing a climate-responsive city. The conclusions underline the environmental values of interstitial spaces which render cities more resilient and environmentally sustainable, and the need for adapting planning to the challenges suggested by the interstitial spaces while integrating insights from the different disciplines concerned with the built environment.

Interstitial spaces and the urban condition

Since their origins, cities have been spatially composed of different built-up areas and interstitial spaces that lie between developments. Pieces of countryside, farming land, undeveloped areas and open tracts of different sorts, derelict land, abandoned infrastructure, urban landfill, large public spaces, geographic accidents, etc, configure an eclectic mix of in-between land that has been addressed by the literature in a very fragmentary way. Indeed 'urban interstitial spaces are often defined as anti-space, latent space, or dormant spaces' (Hugo & du Plessis 2020: 591), while they are also described as vacant land (Ige & Atanda 2013), urban voids, undeveloped (or underdeveloped) areas, open tracts, derelict land, leftover spaces, unbuilt land, *terrain vagues* (Mariani & Barron 2013, Solá-Morales 2002), wildscapes (Jorgensen & Keenan 2012), non-urbanised areas (La Greca *et al.* 2011), or inter-fragmentary spaces (Vidal 2002) *inter alia*. These spaces, however, are far from being empty, abandoned, or derelict; rather they are spatial gaps in the urban fabric regarding their surroundings. In that sense, a low-density neighbourhood situated within a highly densified area is also interstitial. This situation is observed in various cities in China and Hong Kong where low-density neighbourhoods are surrounded by high-rise buildings; an interstitial density that allows further growth and adaptation to contingent issues of housing shortage or climate change (Lu *et al.* 2017). Considering this variety—and a means of unifying the understanding of such spaces—the term 'interstitial space' is used in this paper to generically denote any kind of in-between space that emerges as 'a gap' that is not clearly coalesced into the city's fabric. As such, the interstices contribute to the city's porosity and the production of available space for further adaptation capacities and change.

Interstitial spaces have become significant and may be on the increase in the context of urban shrinkage (Dubeaux & Sabot 2018). They represent a considerable proportion of the urban hinterland in some Latin American cities. The vacant land of Rio de Janeiro alone defines around 44 per cent of the total municipal area, while it is 21.7 per cent in Quito. San Salvador shows 4.65 per cent vacant sites, although the authorities also count areas of informal occupation that are included in the list to be demolished, reaching a total of 40 per cent of whole urban space. In Buenos Aires, vacant land represents 32 per cent of the metropolitan area (Clichevsky 2007), while in Santiago de Chile it is close to 19 per cent (Cámara Chilena de la Construction 2012). In the case of American cities an average closer to 15 per cent has been reported (ibid). These percentages are mainly concentrated in suburban, peri-urban, and fringe-belts areas—all constitutive of urban sprawl contexts—which poses important questions regarding the unsustainable character of sprawling suburbanisation as it nevertheless represents a major source of infrastructural and environmental assets (Gavrilidis *et al.* 2019).

In this vein, focusing on interstitial spaces within processes of sprawling suburbanisation becomes relevant, considering that urban sprawl is determined by increasing rates of land fragmentation (Inostroza *et al.* 2013). More importantly—and against most orthodoxies—urban sprawl has become the home of most of the worldwide population. Although demographic projections indicate that most people live in urban areas, 'the majority of the world's population is actually suburban in location' (Phelps 2021: 345). This makes urban sprawl more significant in terms of how interstitial spaces can determine the potential sustainability of urban systems. This role can indeed go beyond established narratives of retrofitting, to implementing climate change adaptation and mitigation strategies. Thus, leaving interstices unbuilt (or less built), empty, or simply opened to wild urban nature (Gandy 2011, 2013) suggests alternative modes of production of the space as a synonym for *built-up*. Politics around the role of interstitial spaces as empty land can indeed counteract the negative connotation of urban sprawl as a 'disorganised urban' (Phelps 2012) as this is mainly associated with what has been built rather than what is left in-between. As Sievert suggests (2003), 'instead of talking dismissively about urban sprawl, we could recognise that there is a fine-grained interpenetration of open space and built form and see the open space as the binding element, with its new creative potential' (49). Thus, the role of interstitial spaces in activating new expressions of urban nature and public space reinforces the character of cities as environmentally diverse and non-continuous environments.

The interstitial spaces also provide space for social interactions and contact with nature at different scales and with different levels of relationality. Urban interstices can separate communities as well as bridge them while acting as intersections, boundaries, and borders (Iossifova 2013). As such, they can be politically mediated to improve the social and environmental resilience of cities while reinforcing their urban character (Kaika 2005). This conceptual reflection has been advanced by Storper and Scott (2016) who dispute the generalisation of cities as 'urban systems' *per se* and place the role of interstices as key elements of cities. They argue that 'cities' are a very specific form of urbanisation that 'formally represent the geographical containers within which contemporary human society unfolds' (1117), while the 'urban' emerges as 'the organic divisions of labour in which social and economic life (that is, the production of goods and services, but also including cultural, religious, and governmental pursuits) is organised and reorganised within networks of specialised but complementary units of human activity' (1116). Notably, these organisations are not exclusively placed in 'the city', but within what the authors coined as 'the urban land-nexus'—an ostensibly neutral interstice—which 'corresponds to the essential fabric of intra-urban space' (Scott & Storper 2014: 8). In this space, there is a partial or total absence of effective mechanisms of collective coordination that define 'numerous kinds of disfunctionalities ranging from infrastructure breakdowns to locational conflicts, and from deteriorating neighbourhoods to environmental pollution' (9). Thus, while the interstices are 'urban' in nature, they cannot necessarily be part of 'the city' as such. Despite this, interstices can contribute to the urban character of cities precisely through their condition as devices that absorb changes, climate adaptation, allow further growth, and improve environmental resilience and other processes that support the city's sustainability (French *et al.* 2019).

At a wider scale, insights from 'planetary urbanisation' (Brenner & Schmid 2014) entail that the scale at which interstitial spaces are manifested includes those rural hinterlands between cities and regions. This extensive realm is again not an inert space, but the extension of the urban condition manifested in the city in which 'the urban cannot be plausibly understood as a bounded, enclosed site of social relations that is to be contrasted with nonurban zones or conditions' (750). Koolhaas (2021) also noted that 'the countryside' is a space that affects the resilience and adaptation capacities of cities as currently determined by the size of architectural artifacts, functions, economic processes, technological innovations, and environmental impacts that have no precedents in human history (Koolhaas 2021). Thereby, the rural space between (and beyond) cities emerges as a colossal landscape that is not only infrastructural but also cultural and environmental. Insights from urban political ecology touch on these issues when suggesting that 'urban areas have been exploding relentlessly beyond their boundaries, producing a highly uneven urban fabric that ceaselessly extends its borders across non-urban geographies' (Arboleda 2016: 234). These interstitial spaces between urban agglomerations are indeed the scenarios of some of the most radical environmental alterations and 'alert us to the fact that the metabolic exchanges of matter, energy and capital required to feed the contemporary urban world have been distorted and up-scaled to the point that they have now reached a hypertrophic, global extent' (234).

Interstitial spaces can be manifested at different scales ranging from narrow intra-urban spaces—such as the abandoned space between two buildings—up to conurbation zones between two or more city-regions. As such, they influence the way cities respond to environmental changes and, thus, how cities sustain their urban character. Evidently, interstitial spaces offer an alternative analytical point of entry into studies of urbanisation, suburbanisation, and urban sprawl, and call 'for the development of theories of urban politics beyond the city or the urban as a single undifferentiated unit' (Phelps & Silva 2017: 1219).

The relationality and morphology of interstices

One aspect that influences the adaptation capacity of interstitial spaces and their integration into the city's dynamics is their relationality. It has been documented that some interstices are more disconnected from the city's fabric while others are fully integrated, even when their property regimes do not allow any form of occupation (Brighenti 2013). At a regional scale, some interstices operate as bridge areas among distant clusters of economic trade (Zhang & Grydehøj 2020), while others are disconnected from their areas of influence. This is the case of mining activities located between cities that have an environmental impact in surrounding villages and towns (Arboleda 2020). As such, the interstices can be beneficial at large scales of economic exchange while detrimental at scales of proximity. Similarly, interstices defined by heavy infrastructure—such as motorways or railway lines—emerge as physical divisions and restricted areas for nearby communities while their intensive provision of mobility might signal significant economic potential at regional levels (Figure 1).

To understand the relationality of interstices, it is necessary to revise the role of infrastructures and their morphology. Rodrigo Vidal's notion of 'inter-fragmentary space' helps in indicating that 'the urban phenomenon is essentially a permanent tension between fragments' (Vidal 2002: 150): a tension triggered (or supported by) different types of infrastructures and relational mechanisms. According to Vidal, the relationality of the inter-fragmentary space ranges from very narrow infrastructures—such as a fence between two sites—to a wide range of transport connections between towns. When the inter-fragmentary space becomes functionally autonomous, it becomes 'an interstice'. As such, 'the interstice' is not a mere leftover space but a place of transition and change; an incomplete and pending space with its own temporalities (Vidal 2002). Similarly, Meijers and Burger (2017) identify a transitional interstitial zone around cities named the 'Functional Urban Area' (FUA) wherein different economic and environmental processes occur. The FUA can also be amalgamated with other transitional zones that determine the 'Potential Integration Area' (PIA) (Meijers & Burger 2017). This relational potential of interstices highlights 'the inseparability

Figure 1. An infrastructural interstice at the boundary of the communes of Cerrilos and Pedro Aguirre Cerda, Santiago de Chile (author's photo, 2014).

of analytical perspectives and normative agendas on urban dynamics as much as the built environment' (Phelps & Silva 2017: 1219).

In morphological terms, a physically bounded interstitial space—with no infrastructure of connectivity or restricted access—appears less relational regarding those with spatially permeable boundaries. These elements—boundaries and functions—influence the role of interstices as mediators or barriers between surroundings. This could be the case of a military installation, a security buffer, a power plant, an industrial facility, or a non-urbanised island within a system of urbanised archipelagos (Zhang & Grydehøj 2020). Planning policies felt in the urban fringe belt have also determined the morphological features of interstices. The promulgation of macro-scale plans designed to preserve open land—such as the 'Five-Finger Plan' of Copenhagen (Caspersen *et al.* 2006) or the 'Green-Heart' project in Netherlands (Salet & Woltjer 2009)—illustrate interstices as planned spaces with a clear morphological pattern that articulate varied social, political, and economic forces as part of 'the urban'. The emergence of suburban interstices in Latin America, however, derives from a more liberal approach to land planning (Silva 2019) that defines urbanisation in specific locations and, thus, the interstices are randomly distributed in the city (del Castillo & Sopla 2018). The competing economic, social, and environmental values adhering to interstitial spaces ensure that some of them—including those attractive to the private sector—remain pending for prodigious periods of economic growth or financial stability (López-Morales *et al.* 2019). Other factors relate to the emergence of informal settlements mainly fuelled by natural growth and rapid internal and cross-border migration (Sandoval & Sarmiento 2020). The informal settlements define morphological patterns that clearly contrast with those determined by institutional policies or technical macro-scale plans. These differences in the policy framework that produces interstitiality also determine their transition to become urbanised or remain interstitial. This ambivalent condition (urbanised/non-urbanised) highlights the temporal (and spatial) ruptures in the urban fabric (Sola-Morales, 1995) and explains the random spatial distribution of interstices with an unpredictable morphological pattern. The fact that 'an unintended fringe belt may contribute as much to the legibility of a city as a fringe belt with a planned feature' (Whitehand 2001: 108) confirms both the planned and unplanned morphology of interstitial spaces.

The obsolescence of industrial facilities and functions also determines the morphology of urban interstices. Cities that have entered into economic decline and loss of population—such as Detroit or some 'ghost towns' in China (Batty 2016, Xie *et al.* 2018)—may indeed show an increase in interstitial spaces (Dubeaux & Sabot 2018). Here, interstices appear as unused sites resulting from the obsolescence of previously active built-up areas. These spaces become nevertheless significant as they provide accessible land for spontaneous functions, urban nature, and use of open space. Indeed, it has been demonstrated that 'with shrinkage and numerous demolition programs, vacant spaces became very important' (8) considering demographic decline that at least balances the proportion of open space for the remaining population. In extreme situations, the excessive emergence of abandoned sites and infrastructures all over the city can trigger a spiral of population decline associated with crime and squatting. If this process extends beyond what can be controlled—which is the case of the 'ghost towns'—the emptiness can absorb large urban areas that makes an entire city interstitial (Skidmore 2014). De Solá-Morales' *terrain vague* characterises these abandoned and obsolete infrastructures as 'vague' in the sense of empty—without activities or functions—and in a clear stage of ruin. These spaces are imprecise, undefined (a 'form of absence'), and without fixed limits or future destinations (de Solá-Morales 2002). The importance of these spaces relates to their significance as pieces of history and collective memory (Gandy 2016), and their environmental functionality to balance water flows and control water streams during extreme rainfall events (Li *et al.* 2014).

The environmental flexibility of the interstices

In 1993, the Dutch architect Rem Koolhaas proposed the term 'nothingness' to elucidate the spatial character of Berlin after World War 2. The city was shaped by different survival of built-up spaces interspersed with urban voids resulting from the destruction of the city. These voids—with no architecture or development of any kind but only ruins—amalgamated the fears of the past with the hopes and optimism of the city's reconstruction. This optimism relied on the authorities' willingness of filling the voids with new urbanisations. However, Koolhaas contested institutional attempts to reknit the damaged urban fabric by filling the voids arguing that any attempt would bury the scars of the city, its recent history, and, most importantly, the still unknown opportunities ahead. The architect expressed this by indicating that 'where there is nothing, everything is possible; where there is architecture, nothing (else) is possible' (Koolhaas, 1995: 199). Alternatively, Koolhaas contended that Berlin is now divided and dispersed, a decentralised city in which the urban voids express Berlin's new character of a dazed, fragmented, and destroyed land with no centre. For Koolhaas, the future of Berlin must precisely operationalise the destruction (or deconstruction) as a mechanism that (re)creates the character of Berlin, and even creates new voids by demolishing dysfunctional parts. This operation would leave space for the wild forest to grow and create a place in which isolated (and somehow hidden/desolate) islands of infrastructure and ruins are dispersed. Koolhaas proposed a city in which the built-up space would float within a large empty space of 'nothingness': the new urban condition for Berlin defined by unplanned and planned interstitial spaces.

Following Koolhaas's imaginaries on Berlin—and the implications of urban voids in the socio-political agenda—the emergence of interstices ostensibly seems to be a matter of intended design as well. Interstices can be planned as flexible spaces for growth, functional fluidity, attraction of wildlife, and improvement of absorption capacities in storm events and other natural disasters (Hugo & du Plessis 2020). Moreno-Pessoa *et al.* (2016) argue that it is possible to make some cities more resilient by enhancing the urban porosity determined by the interstices, although other cities can be led to socio-spatial segregation as porosity has different effects in different contexts. The authors indicate that 'what is a challenge in one urban system may become an opportunity in a different system' (48). Therefore, porosity must be carefully analysed before implementation, in regard to specific levels of socio-spatial segregation, exposure to natural disasters, and lack of open spaces. Implementing urban interstices can separate communities, but also facilitate the co-existence of functions and the expansion of services in key locations (Viganò 2013). Interstitial spaces can also operate as public venues in periods of normal functionality, or as public shelters in the emergency of an earthquake, flooding, storm events, etc (French *et al.* 2019). However, it is important to emphasise that the flexibility of interstitial spaces in hosting multiple functions—and their capacity to adapt to and absorb changes—not only relies on its spatial aspects but also on the regulatory constraints imposed by planning regulations. To an extent, undeveloped land represents natural or regulatory constraints that can be unlocked (Dubeaux & Sabot 2018).

On this basis, the environmental flexibility of interstices still emerges as the primary factor for spatial adaptation considering that planning and policy constraints 'are social or regulatory constructions which can be unmade or are natural features that could be "improved" or "reclaimed" to allow development' (Phelps & Silva 2017: 1204). This environmental flexibility can be determined by the environmental potentials of interstices, their spatial attributes to absorb change, and their scalar and multifunctional character determined by different land uses, morphologies, and infrastructures of relationality.

The environmental potentials of interstitial spaces

It has been clarified that less planned interstices give space for the proliferation of urban wildlife; places where different expressions of spontaneous flora and fauna can flourish (Gandy 2011). This includes abandoned buildings, ruins, or unattended facilities that Jorgensen and Keenan (2012) define as 'wildscapes': places where planning forces of control do not operate at all. Similarly, Gandy's notion of 'wastelands' (2013) highlights the values of abandoned, marginalised, and forgotten spaces characterised by exuberant flora and fauna with both aesthetic and ecological benefits. These interstitial landscapes offer an alternative point of entry into scientific exploration of urban wildlife, nature, climate change, mitigation of flooding and extreme rain; 'wastelands' become valuable gears of urban ecosystem services characterised by specific aesthetics, high levels of biodiversity, random expressions of freedom, hints of history, and spatial novelty (Gandy 2013). These interstices become strategic in minimising pollution, improving climate change adaptation capacities, enhancing contact with nature, and improving overall urban quality and human well-being (Savarda *et al.* 2000). The ecological values of interstices prevent the loss of biodiversity, reduce air and noise pollution, and regulate temperature while diminishing the heat-island affect (Kleerekoper *et al.* 2012). Considering their varied magnitudes, some of them are big enough to ensure the survival of some flora and fauna while smaller interstices provide space for community projects and improvement in community resilience. There are several examples of abandoned parks recovered by local residents, volunteers, local councils, community groups, and non-governmental organisations (NGOs) that are suitable for the implementation of social programmes of urban agriculture, educational activities, domestic animal husbandry, and community engagement (Saunders 2011).

The spatial attributes of interstitial spaces

An emerging approach for planning the interstices relates to the notion of 'sponge cities' (Jiang *et al.* 2018). This idea aims to introduce (or preserve) interstices to increase the city's spatial porosity and, thus, improve its capacity to absorb stormwater. In some Chinese cities, pluvial flood disasters have become a regular hydrometeorological phenomenon and are of increasing concern due to their environmental, economic, and social damage (Zevenbergen *et al.* 2017). For some, these events are caused by climate change (Duan *et al.* 2016), which is driving a significant overall increase in rainfall across most global regions (You *et al.* 2011). Although the concept itself still mainly established in the Chinese context, the underlying planning and design principles of creating permeable surfaces, increasing open spaces, and implementing interconnected green corridors that respond to climate events have been implemented in various Latin American cities (Herzog 2016, Pessoa *et al.* 2016, Vásquez *et al.* 2016, 2019). Thereby, the general objectives of the 'sponge city' could soon be a transnational concept as it offers substantial ways of restoring the city's capacity to absorb, infiltrate, store, purify, drain, and manage rainwater by replicating natural hydrological cycles.

As such, the introduction of interstitial spaces requires a volumetric planning and design approach—beyond bi-dimensional land-use planning—to embrace the three-dimensional character of water cycles, climate components in which the interstices participate, control over varied streams of air, and underlying irrigation design (Moreno-Pessoa *et al.* 2016). At an architectonic scale, studies on urban morphology and residential climate have confirmed the importance of implementing interstices in large densified areas of sub-tropical regions—especially during hot and humid summers—as compact building blocks create stagnant air that worsens outdoor urban thermal comfort (Yuan & Ng 2012). In Hong Kong, for instance, high-rise compact buildings define deep street canyons that create barriers for street ventilation and lack of public open space. Thus, introducing voids 'within' the blocks becomes an opportunity to supply open space for communities (ibid). It has also been argued that porosity can transcend the morphology of buildings to connect with the existing voids of the city (Tadi *et al.* 2017). As such, both the open space of the city and building voids can be integrated into a continuous network of interstitial spaces that can make a difference in terms of resilience and adaptation capacities to climate change. Reference to urban voids as part of buildings' morphology and the city's volume proves the *three-dimensional* potential of interstices, not solely limited to the ground floor level or bi-dimensional conception of land uses (Gallent & Shaw 2007).

The multifunctional character of interstitial spaces

A key aspect of the flexibility of interstitial spaces is their capacity to absorb different functions over time while preserving their original morphology. Studies conducted in Latin America and the Middle East provide enough evidence to illustrate how in some cities the streets become improvised football pitches, while proper football pitches become open spaces for massive events such as music gigs, fairs, celebrations, or temporary markets (Anuar & Ahmad 2018, Uehara *et al.* 2018). A similar situation is observed in some European cities in which vacant plots planned for future extensions of infrastructure or services are used for 'pop-up' functions—functions that operate for a short period of time—that sustain the adaptation capacity of the city (Bertino *et al.* 2019). Other derelict spaces defined by motorways and leftover spaces found in parking lots or neighbourhoods are used as public venues (Endres *et al.* 2014, Milián Bernal 2020). It is argued that 'informality provides an opportunity for those excluded from formal processes to find presence in the city' (Wall 2011: 155) and, thus, reinforce the social resilience of organised (and eventually subversive) groups. In the US and Mexico, it has been demonstrated that, in the context of decreasing food security, large cities can achieve resilience through local food systems, green infrastructure, and ecosystem services by using their intra-urban interstitial spaces (Hare & Peña del Valle Isla 2021). Although these inner interstices are often claimed by local communities, at a regional scale the conurbation space between cities is also reclaimed by different actors and agencies. Recognised as less regulated spaces, conurbations are used for community projects that improve the social and environmental resilience of large regional systems (Yong *et al.* 2010, Živanović-Miljković *et al.* 2012). The factors that explain this capacity of some spaces to absorb different functions are multiple, although there is a certain consensus that multifunctionality can flourish in those less regulated spaces where institutional constraints are somehow absent, away, or are flexible enough to allow alternative temporary uses or 'particular forms of urban practice' (McFarlane 2012: 89).

It is known that interstitial spaces improve the resilience of cities and reinforce their urban condition. If we assume that urban resilience relates to the capacity of an urban system to absorb different types of turbulence, retain substantial functions and structure, and recover its lost functional capacities while undergoing change (Wardekker *et al.* 2020), the porosity defined by the system of interstitial spaces plays a critical role in defining climate-responsive cities that ensure urban sustainability (Figure 2).

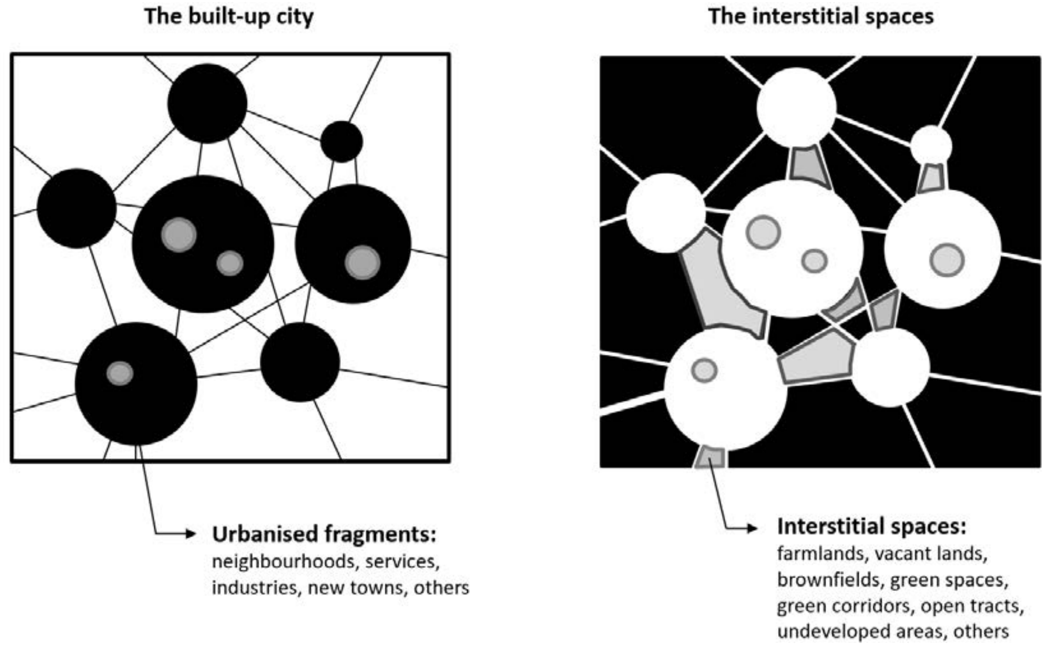

Figure 2. The built-up city and the interstitial geography (author's diagram).

Methodology

Choosing Santiago de Chile's interstitial spaces

The analysis presented in this paper is illustrated through the case of the capital city of Chile—Santiago—specifically focusing on its south metropolitan expansion as it appears to be the most important axis of sprawling suburbanisation (Borsdorf *et al.* 2007). The city is used as a basis for abstraction and generalisation, though the role of interstitial spaces in creating climate-responsive cities has salience to the vast majority of urban areas. Santiago de Chile provides a good example of the significance of interstitial spaces in a context of urban sprawl, specifically as it illustrates common patterns of urban development observed in most Latin American cities (Coq-Huelva & Asián-Chaves 2019). As a metropolitan area, Santiago is composed of 36 independent communes and has a total population of 7,112,808 inhabitants. As such, it represents 40.5 per cent of the country's population (INE 2017) confirming a high national demographic concentration. Santiago's urban development is characterised by a sprawling pattern of urban growth (Silva & Vergara 2021) mainly defined by transport corridors (Flores *et al.* 2017), peripheral concentration of social housing developments (Coq-Huelva and Asián-Chaves 2019), high rates of land fragmentation (Inostroza *et al.* 2013), the presence of active farming areas (Silva 2020), unregulated urbanisation beyond the urban limit (Flores *et al.* 2017), inequal distribution of green and open space (Banzhaf *et al.* 2013), and high-rates of socio-spatial segregation (Cox & Hurtubia 2020). The city reflects planning rationales adjusted to facilitate urban growth supported by privatisation of land and infrastructure (Zegras 2003), and centralisation of social housing supply (Heinrichs and Nuissl 2015). Taken from the southern sprawling space of Santiago—that shows a significant number of interstitial spaces—a few interstices are used to illustrate their environmental values, relationality, and the scale at which they are manifested, and how they qualify Santiago's suburban landscape as a potentially climate-responsive context. The three types of interstices selected for analysis are: a) The 'Huertos Obreros y Familiares de la Pintana' [Worker and Familiar Orchards of La Paintana commune] (a cluster of small-scale agricultural plots; this case is also collated with the nearby farming land of La Platina and Campus Antumapu), b) the extraction mining site of La Florida/Puente Alto, and c) southern metropolitan conurbation space (Figure 3).

The selected interstices describe the previously discussed key attributes of environmentally flexible spaces (environmental capacity, spatial variety, and multi-functionality) that allow adaptation capacities and mitigation strategies against climate change and natural disasters, and improvements in social and environmental resilience. Aside from the conurbation space—where a lineal axis of about 35 km is

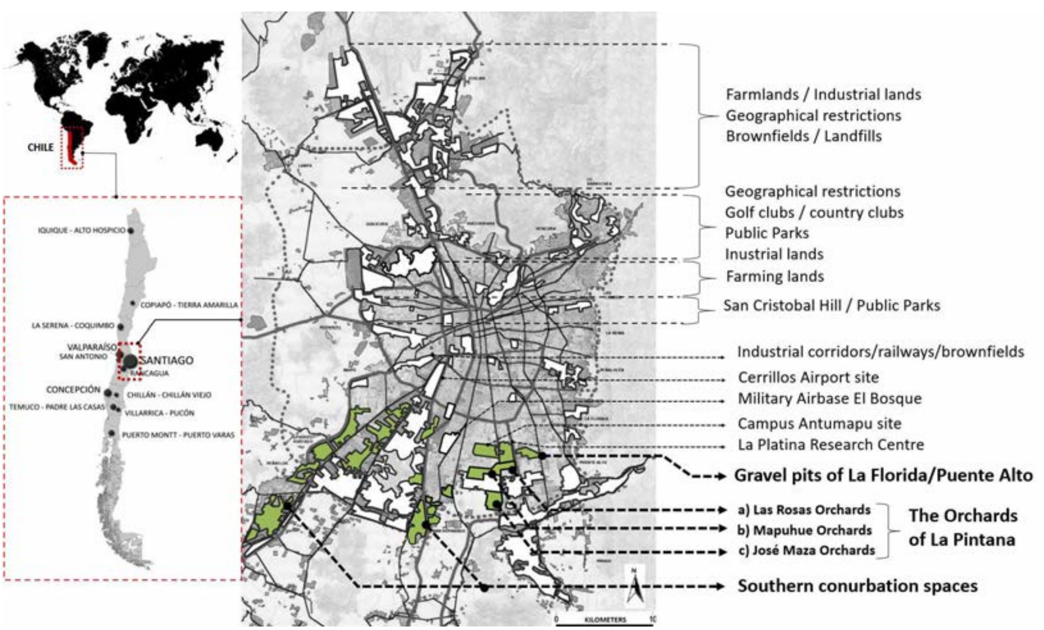

Figure 3. Map of Santiago, its interstitial spaces, and the selected interstices for analysis (author's map).

taken—the orchards of La Pintana and the extraction (mining) site of La Florida/ Puente Alto are about 300 hectares each, representing an attractive size for new urbanisation. These areas are identified by various actors as 'strategic' in light of their location, land capacity, and connectivity, and appear as contested spaces as various public–private agencies operate upon their land management and possible future destinations.

Research design and methods

The findings presented in this paper are the outcomes of case-study research—conducted between 2016 and 2021—based on a mixed methodology that articulated qualitative and quantitative data (Tashakkori & Creswell 2007). Considering the varied spectrum of interstitial spaces, the research adopted a 'multiple case-study approach' (Burawoy 1991, Flyvbjerg 2006) to encompass a representative range of cases and generalise conclusions. The methods included mapping Santiago's urban development and interstitial spaces to analyse its morphological, spatial, and environmental characteristics.

Document review was used to examine policy conflicts and the views of planning authorities on Santiago's urban development and interstitial spaces. This allowed an examination of how urban policies influence the proliferation of interstitial spaces in Santiago. The policy review was based on Bowen's approach (2009) in which documents are politically mediated 'social facts' that provide findings, policy priorities, and interpretations on Santiago's urban development, projects, plans, and synthetised data. The analytical procedure considered thematic analysis (Kiger & Varpio 2020) to organise and codify data and policy narratives into three categories that describe the environmental nature of interstitial spaces: a) *the policy and environmental values of interstices*, b) *the spatial attributes of interstices*, and c) *the functions* (and formal/ informal land uses) *of interstices*. This information was collated with statistics on demography (INE 2017), land and housing market fluctuations, regional economic development, environmental policies, and findings from secondary research on Santiago's environmental sustainability (Evans & Lewis 2018). Selected quotations were also taken and organised into major themes, categories, and case examples specifically through content analysis (Gavin 2008). Consulted reports included *The National Policy of Urban Development* (MINVU 2014a), various statistical reports from the Institute of National Statistics (INE), the *Metropolitan Development Plan of Santiago* (PRMS100; MINVU 2014b) and various local development plans, communal master plans, urban design proposals, reports from the Ministries of Public Works, Environment, Agriculture, and Housing and Urban Development (MINVU) inter alia.

The data found in policy reports were also collated with primary data gathered from fifty-six semi-structured interviews (Galletta 2013, Stender 2017) that included a range of interviewees selected for their first-hand knowledge of Santiago's urban development and the environmental attributes of its interstitial spaces. The interviewees included high-level planning authorities, policymakers (metropolitan/municipal), politicians (deputies, senators), urban designers, developers, local residents, agricultural scientists, and members of social and environmental organisations and NGOs. The datasets of semi-structured interviews generated during and/or analysed during the current study are not publicly available due to restrictions imposed by the ethical assessment of the research (Ethic Application ID: 5588/001 2014, UCL) that required interviews to be anonymised so that the respondents could be frank, without fear of professional repercussions. Questionnaires inquired into three specific subjects related to Santiago's urban development and interstitial spaces: a) Santiago's pattern of urban sprawl, b) Santiago's interstitial spaces, and c) the politics and implications of interstices on Santiago's urban development. Statistical data on Santiago de Chile, Chilean population, housing stock and others from institutional sources are publicly available through the links indicated in the reference list of this paper.

All the information was corroborated and complemented through site visits where direct observations were undertaken to evaluate the urban quality, physical infrastructure, accessibility, spatial boundaries, land uses, (in)formal occupations, quality of surroundings, relationality, and environmental characteristics of selected interstices. Since secondary research on these sites is limited, site visits were necessary to obtain a comprehensive understanding of existing environmental conditions. The visits were based on Rayback's approach, who indicates that observations, visual records, and measurements make it possible to address more than one site to compare and contrast, establish commonalities and differences, and test whether or not a site finally meets the study goals (Rayback 2016).

The interstitial spaces of Santiago's urban sprawl

Santiago's urban sprawl describes a wide spectrum of interstitial spaces recognised as diverse in terms of morphology, size, location, and environmental properties. The types of interstitial space found in Santiago include agricultural and industrial land, brownfield, landfill, public spaces, geographical restrictions, conurbation zones, former airports, military facilities, small-scale farming areas, research centres, infrastructural spaces, and buffers of security inter alia. Some of them are currently well located near transport, energy supply, services, and populated surroundings that make them attractive for both public and private investments. As such, they are perceived by different agencies and social-based organisations as an opportunity to change suburban inertia mainly driven by the social housing agenda. The diversity of Santiago's interstices also relates to their origins and multilevel modes of governance, as some interstices are outcomes of land privatisation, financial speculation, geographical and physical constraints for urbanisation, planning restrictions, and disparities between landowners and public agencies regarding their future destinations (Silva 2019). Given that some interstitial spaces describe agricultural land-uses, for instance, they are managed by the Ministry of Agriculture although immersed within the suburban fabric they are also part of the plans of the Ministry of Housing and Urbanisation (MINVU).

In Chile, aggressive policies of land privatisation over the past forty years have increased land subdivision, thus resulting in the creation of clusters of small properties that affect large-scale interventions (Santiago *et al.* 2016). In this scenario, some landowners agree to develop their land while others do not. This ends up creating clusters of built-up areas mingled with interstices. Conurbation zones are also examples of large areas driven by transport infrastructure and de facto developments that define a pseudo-urbanised landscape where different uses are interspersed with undeveloped land. As mentioned, gaps in governance also determine the emergence of interstitial spaces. These are the cases of shared boundaries between different municipalities in which local authorities tend to leave them without services, houses, or any kind of infrastructure. Local mayors place their interventions in central areas to serve their own taxpayers and voters, thus ensuring that local residents perceive the benefits of their political leadership (Silva 2019). Regulatory constraints also define 'restriction zones' as areas where urbanisation is prohibited. This is the case with ecological reserves or protected historical sites. Other factors that encourage private landowners to keep their land undeveloped over time include land banking and land speculation (López-Morales 2011).

As proposed in this paper, the environmental approach to studying the interstices is structured by the environmental values of interstices, their spatial attributes, and their flexibility to adopt different functions at regional levels. In the case of Santiago, this approach will be examined through the cases of farming land, the extraction mining site, and the conurbation space.

Santiago's suburban rurality: the orchards, La Platina, and Campus Antumapu

For scholars and consultants on environmental sustainability, the southern interstitial spaces of Santiago appear to be 'healthy spaces'. As such, they contribute to the ratio of open space that diminishes the impacts of urban pollution. In this category, suburban farming plots have a key role in providing green space, clean air, quiet environments, and workplaces for local communities. These types of rural interstices are mainly located at La Pintana commune—recognised as the commune with the most fertile land in the whole metropolitan region (ODEPA 2012, SINIA 2012). These interstices are used for agricultural production, but nevertheless experience tension from planning demands linked to housing shortages. These are the cases of La Platina site (Ministry of Agriculture), Campus Antumapu (Universidad de Chile), the Tocornal and Concha y Toro vineyards, and the 'Huertos Obreros y Familiares', all recognised as 'foodscapes' by NGOs, the Food and Agriculture Organization, and social organisations. Considering their current location within the urban hinterland, these interstices have become seminal expressions of 'urban agriculture' and natural heritage related to historical practices in agriculture and social housing (Roubelat & Armijo 2012).

The most prominent example is the above-mentioned 'Huertos Obreros y Familiares'—a cluster of half-hectare orchards created in the 1940s and named *Las Rosas*, *Mapuhue*, and *José Maza.* The orchards have become a self-contained environment where families cultivate food to ensure their own subsistence and to distribute to the metropolitan region. These interstices define a category of suburban rurality wherein urban and rural identities coexist (Catalán *et al.* 2013). Despite development pressures, the land is protected by Law 6.815—enacted in 1941 (known as 'José Maza Law')—which has ensured its preservation over the years as it does not allow land subdivision. The orchards have been historically managed by the original families and their descendants, and after years of cultivation they have been recognised internationally for the provision of organic, healthy, and seasonal food (Figure 4). They help to reduce the temperature of the whole metropolitan region through evapotranspiration, showing a difference in temperature of 4°C in comparison to neighbouring communes. The orchards also ensure natural irrigation by surface water, avoiding flooding, which makes the commune comparatively more resilient (interview with the Director of Environmental Operations. Municipality of La Pintana, June 2014). This is a recognised trait in a city like Santiago where the loss of green spaces implies a significant loss of infiltration, cooling, and retention capacities that leads to greater hazard exposure (Krellenberg *et al.* 2013).

Several studies have confirmed the importance of the orchards, considering the scarcity of green spaces in Santiago and the unbalanced distribution of green infrastructure among suburban municipalities (Escobar 2006). For planners and developers alike, this disparity must be combatted through their preservation as they help in decreasing environmental injustices. For scholars, policymakers, and social organisations these interstitial spaces can be part of a wider interconnected system of public venues that integrate the spectrum of derelict and undeveloped land with the city.

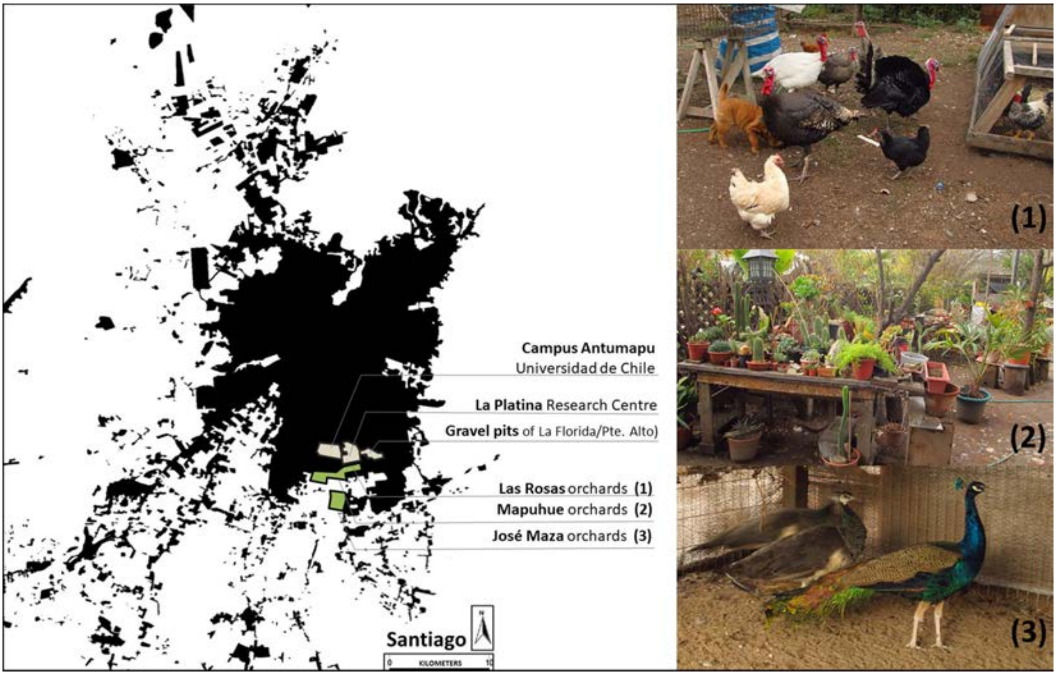

Figure 4. Location of the agricultural sites of Campus Antumapu, La Platina, and the 'Huertos Obreros y Familiares' of La Pintana [Workers and Familial Orchards] (author's map and photos, 2020).

> *The orchards of La Pintana as interstitial spaces within southern Santiago have an enormous environmental and educational impact, which can be amplified if connected to other places and the surrounding neighbourhoods. You can take the kids there to see the spiders, animals and birds, or simply to enjoy the wild nature or reinforce their social relationships. Unfortunately, internal rural spaces (as almost everything) are seen as 'commodities' and when they are not productive, they become urbanised. So, their intangible values are not included in the economic equation although they must* (interview with Professional Advisor, National SEREMI of Agriculture 2010–14, May 2014).

This integration implies '*a modernisation of the Chilean planning system to include the intangible and hedonic value of interstices, and appeal* [against]*the capitalist agenda that is known to commodify the land. This would affect the taxation system by including criteria of environmental and socio-cultural benefits*' (interview with the Director of Urban Project Ciudad Parque Bicentenario, MINVU, May 2014). It is argued that the orchards can be connected to several local hills, valleys, and even cliffs. This, in turn, adds spatial complexity to the city by incorporating further functions related to leisure, education, sport, and appreciation of nature.

> *These interstitial spaces provide natural soil that should be maintained, even when they are not agriculturally productive. The unique experience of seeing the trees is a value in itself. There is a difference between 'value' and 'price', and natural spaces such the orchards of La Pintana matter because of their 'values'. These spaces also have a history to be preserved that could be part of the heritage for future generations* (interview with the President of the Water Community Villa Las Rosas, La Pintana, June 2014).

For residents, these interstitial spaces can host activities such as camping, swimming, different types of sports, and city farms, typically found 'outside' the city. These functions can improve social acceptance of Santiago's sprawling context and, thus, its social resilience. '*Suburban families that cannot afford to activities outside the city could use these interstices as alternatives for leisure and recreation*' (interview with Professional Advisor, the National Service of Environmental Evaluation. Ministry of Environment 2014). The cases of La Platina and Campus Antumapu—also at La Pintana commune—describe a strong 'provincial atmosphere'; these are landscapes where it is possible to see the Andes Mountains, the trees, the sun, and the skyline of the city (Figure 5). Local residents perceive these places as natural references for how seasons change during the year; a privilege for low-income families that are unable to go outside the city to enjoy nature:

Figure 5. La Platina site, La Pintana commune (author's photo. May 2016).

> *La Platina is a piece of countryside within the fully urbanised area … good to have a diverse landscape in which open spaces offer beautiful views; a break in our homogeneous routines. This space* [La Platina] *can be a park, which is not only a public space for the area but also for Santiago. These areas should remain open as we have a lack of green space and our homes are quite small. In my case, for instance, I used my small private yard to build a roof for the car! That was the end of my own little open space … and is the same for everyone here. So, these interstitial spaces are the best chance to supply green space for everyone. This really makes us stronger as community to overcome economic and social difficulties* (interview with resident of Villa Ambrosio III, La Pintana commune. June 2014).

These spaces also add value to surroundings and influence decision-making when choosing a place to live. These values relate to the presence of nature and how it provides specific features and identity to the area. They are also perceived as safer in a country that is vulnerable to flooding and other natural disasters, and where the agenda of risk management has become a national priority:

> *When we arrived here* [ten years ago] *this place* [La Platina] *was fenced. So, we received the house from the government with a beautiful landscape in front of us … a place covered by plants, vegetables and flowers. Actually, the most amazing views were those of the marigolds that made the landscape so beautiful. These places make our neighbourhood more beautiful. It was one of the reasons why we agreed to come here. It is a huge place in which you can find the openness … and that's why our neighbourhood is never flooded. This is also a place we use to escape when there is a shake* [earthquake]. *We just run into the site and we are all safe!* (interview with resident of Villa San Gabriel, La Pintana commune, June 2014).

Santiago's three-dimensional landscapes: the extraction (mining) pits of La Florida

The presence of industrial land in southern Santiago defines a category of interstitiality that contrasts with the homogeneous (plain) suburban landscape of social housing developments. In particular, a series of interconnected gravel pits located in the boundary between the communes of La Florida and Puente Alto cover an area of about 300 hectares. The pits have been used to extract raw material during the last fifty years. Due to the continuous excavations, the resulting landscape is an uneven geography of interconnected 'holes' of different lengths, widths, and depths. The stones, gravel, rubble, etc also contribute to define a landscape that clearly contrasts with the housing developments that surround the pits. Somehow, these pits have become the backyard of many houses located just in the border. These homes have gained privileged views over the system of interconnected gravel pits although reported accidents relate to the lack of fences, electric light in the night, security, and anti-social behaviour (interview with the Director of Urban Planning, La Florida commune, June 2014) (Figure 6).

Figure 6. The interconnected extraction sites at the boundary of La Florida and Puente Alto (author's photo. May 2016).

The pits are a cluster of private properties in the hands of different owners—with restricted public access—and in which extraction of raw material is combined with industrial storage of rubble. The industrial activities interfere in the lives of local residents who complain about air pollution, noise, and lack of safety given that the site does not have proper fences against the deep excavations. Although extraction has dwindled to a now negligible activity alongside some very minor construction-related activities, the area remains classed as 'industrial' but is effectively an interstitial space. As decaying or blighted spaces, the pits are nevertheless 'pending'; framed by variable timelines over which they may become developed at some point. Additionally, this space suggests unprecedented coordination at multiple levels resulting from its location in a boundary area.

Aside from its morphological attributes, the pits are also recognised as large and efficient bowls of collection of local and metropolitan stormwater. At municipal levels, it has been calculated that a substantial fraction of superficial water ends up in the pits. This situation triggers differing ideas regarding future reconversion: while some central and local authorities advocate filling in the pits to relocate more social housing developments, others see the pits as a future metropolitan park that can both absorb stormwater and provide communal green space (interview with the Chair of Urban Planning of the Municipality of La Florida, May 2014). Studies conducted by the MINVU in 2001 defined the area as suitable to be connected with other neighbouring interstices—La Platina and Campus Antumapu—and proposed a metropolitan park with a total intercommunal space of around 794 hectares. As such, the park would benefit about 1,100,000 inhabitants (Figure 7). Environmental assessments indicated that the provision of green spaces would serve as an efficient receptor of superficial flooding that would improve the metropolitan resilience:

> *It was determined that the area should be intended to create a large ecological recreational centre … a mega-park, a park of the southern zone. This would also balance the lack of green space and would provide drainage for large flooding in winter. It is known that in the south we have in average less than 9m² of green space per person—far below what is indicated by the WHO—but after doing these studies we realised that the whole environmental performance of the area can be improved, including flooding adaptation. We concur with central authorities in also having here the metropolitan zoo—so, we applied to host it at La Platina* (interview with the Director of Urban Planning of the Municipality of La Platina, May 2014).

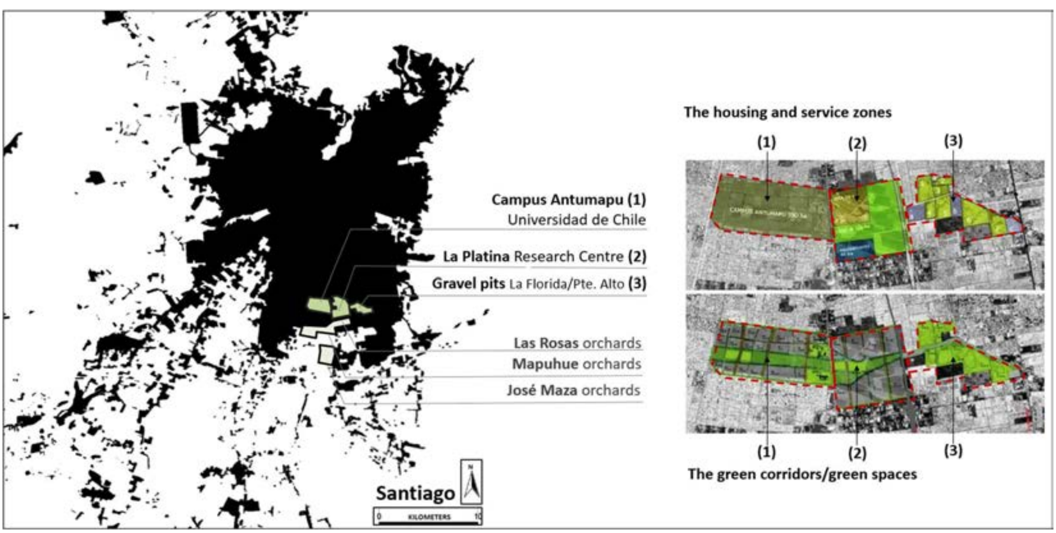

Figure 7. Master plan of the 'Parque Sur' project connecting the sites of Campus Antumapu, La Platina, and the extractions sites of La Florida/Puente Alto (author's map, based on *EMB Construccion Magazine*, 2016).

La Platina would also witness better housing projects, and the Antumapu site would remain as a large-scale green area. According to local authorities, the transformation of these interstices into a large interconnected park would define a symbiotic relationship with the communal rural functions:

> *This commune is in a very good position to address these challenges and contribute to the maintenance of the metropolitan zoo and the park. Why? Because 50 per cent of our commune is rural, and we are able to produce food for the animals and provide maintenance. This is a unique condition as we have the rural plots and the urban farmers* [huerteros]. *With our know-how and technicians there is no doubt that we would be more socially and environmentally sustainable* (interview with the Director of Environmental Management of the Municipality of La Pintana, June 2014).

The multifunctional regional interstices: the southern conurbations

The southern conurbations of Santiago define another category of interstitiality that illustrates different relationalities, morphologies, and resilience capacities. Despite appearing as open spaces, they are formed by different sub-interstices and built-up areas with different functions. Santiago's southern conurbations are a complex mix of unregulated and regulated land that define an ambiguous landscape in which housing projects, farming areas, and infrastructure coexist.

Owing to the infrastructure and lack of constraints on rural land, the resulting in-between spaces become accessible to new developments that diminish the environmental capacity to manage superficial flooding in these zones. This has been noticed by private owners of industries and housing developments, although they do not see themselves as contributors to this environmental deterioration (interview with the Chair of Urban Planning of the Municipality of San Bernardo, May 2014). Cases in points include the conurbations between Maipú and Padre Hurtado—structured by the 'Autopista del Sol' [The Sun Motorway] and 'Camino a Melipilla' [Melipilla Road]—as well as the conurbation between southern Santiago and San Bernardo structured by the 'Autopista Central' [Central Motorway] (Figure 8).

The first conurbation between Maipu and Padre Hurtado is primarily explained by the growth experienced by the commune of Maipú— that along with Puente Alto—has concentrated 70 per cent of the increase in population after 1978. These were the two most populated communes in Chile between 1982 and 2002 (Tokman 2006). Empirical studies show a clear concentration of social housing units in these communes between 1979 and 2002 (Hidalgo 2007, Tapia 2011)—with an increase in communal land prices (Brain & Sabatini 2006)— that derived into the inclusion of these communes in the last modification of the Metropolitan Regulator Plan of Santiago (PRMS100; MINVU 2014b). In 1994, the urbanised area of Maipú reached

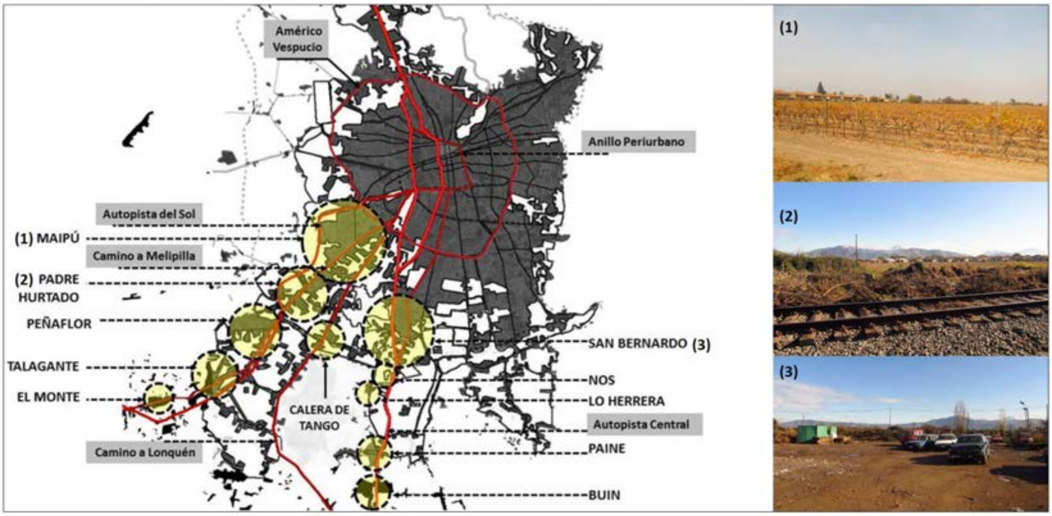

Figure 8. Santiago's southern conurbations and the common sub-interstices of Maipu, Padre Hurtado and San Bernardo (author's map and photos, 2020).

the boundary of the neighbouring commune of Padre Hurtado, which was also included in PRMS100. By diminishing the hectares of rural land, this rapid growth has confirmed sprawling growth with strong connection to environmental hazards for Santiago de Chile (Krellenberg *et al.* 2013). However, one of the most recognised characteristics of Maipú and its conurbation space is its adaptation to these drastic changes, their increasing multifunctionality, and general improvement in urban quality. Here, farming areas, infrastructure, upper-class residential developments, low-income neighbourhoods, industrial facilities, open spaces, educational and commercial services, research centres, historical heritage, green infrastructure, sporting clubs, small villages, etc, shape 'a collage' of elements that speak about flexible planning restrictions, the supremacy of land tenure, and transport corridors as main determinants of the overall morphology.

The second conurbation space is derived from the expansion of the neighbouring southern commune of San Bernardo. The commune is also included within PRMS100—a modification that increased the communal land from 5,400 hectares to almost 9,000 hectares (more than a 70 per cent)—aimed at absorbing around 64 per cent of residential growth (Boccardo 2011). San Bernardo had to change its urban limits to include more housing developments, green spaces, connectivity, and the reconversion of industrial land. The commune is considered a 'sub-centre' of Santiago: an area with high levels of functional self-sufficiency (PLADECO 2011). The plan includes a small rural village called 'Lo Herrera'—a distance of 15 km from San Bernardo's city centre—and other in-between rural plots for future growth. Some of these land are labelled 'special uses', and others are security buffers, underused infrastructure, military installations, and sports facilities. Some geographical handicaps—such as the Cerro Chena and a large gravel pit—appear as geographical restrictions; others as abandoned spaces that '*can be part of the environmental assets of the commune if properly included in metropolitan plans*' (interview with the Chair of Urban Planning of the Municipality of San Bernardo, May 2014). The commune is recognised as one that is experiencing the most radical changes in its rural identity, mainly marked by the extensive location of social housing developments (J.M.E. Vidal 2020).

As seen through the case of Santiago and the selected interstices, the analysis of interstitial spaces can be addressed with regard to its environmental potential, spatial attributes, and multifunctional capacities at regional levels. The case of Santiago de Chile sheds light on the role of interstitial spaces in contributing to the social and environmental resilience of cities, and their spatial and functional adaptation. The theoretical approach and the case of Santiago also provide a more comprehensive understanding of the nature of interstices as spaces that are not only 'green'. In that sense, the research contributes to amplifying the spectrum of land that can be considered part of the environmental assets of cities, usually addressed by closely related literature on green infrastructure, natural capital, environmental services, and urban sustainability. The studies of interstices can involve a more interdisciplinary approach to also complement the literature on suburbanisation, urban sprawl, and urban governance for the improvement of community resilience and the preservation of multiple environmental assets. In the case of the orchards, for instance, bottom-up initiatives counteract hegemonic modernisations driven by the massive production of social housing, market-driven infilling policies, and the use of vacant land for regional transport infrastructure. In the case of the mining site of La Florida/Puente Alto, the uneven geography resulting from the extractive activities provides a spatial and environmental variety with enormous potential to absorb functional and environmental changes at local and metropolitan levels. If integrated into planning, it can inspire innovative design solutions to absorb extreme rainfall while providing a large-scale public space. However, this case unveils the inertia of planning aimed at undertaking urbanisation on level ground and thus promoting re-filling rather than adapting policies to accept its interstitial condition. Finally, the conurbations pose major environmental and governance challenges considering their piecemeal consolidation as hybrid spaces composed of urban and environmental assets. Their multifaceted nature in terms of infrastructure suggests further reflections around their autonomy as distinctive geographies of regional significance. Here, multifunctionality, environmental hybridisation, and specific forms of rural–urban practices are natural features that dispute the notions of suburbanisation and rurality. Contrary to what the interstices suggest, however, the political impulses to 'fill the gaps' reflect a long-standing will of modernist-inspired nations—driven by the values of a neoliberal agenda—that codifies the interstices as wasted land rather than environmental assets that must be preserved (Phelps 2015). Indeed, the intense concentration of social housing developments and the implementation of regional motorways in the south axis of Santiago may account for the scale of the subsequent dysfunctionalities of suburban sprawl; all contradictions in the accumulation process now have to be addressed by further rounds of state interventions—such as the new version of the NPUD/2014 (MINVU 2014a)—which interstitial spaces are not part of.

The approach proposed in this paper—structured by the environmental potentials of interstices, their spatial attributes, and their multifunctional capacities to absorb changes and mitigation strategies—has salience to the vast majority of cities characterised by processes of land fragmentation and urban sprawl. The findings presented here can also serve as a reference for an analysis of cities where the spectrum of interstices varies in quantity and type. In that sense, other cities can contribute to bulk up the repertoire of interstitial spaces along with their varied environmental implications and the politics associated with the type of resilient suburbia that they suggest.

Conclusions

Although less recognised in the planning literature, the interstitial spaces that are produced alongside the urbanisation process are substantial components of the sprawling geography of city-regions. Ranging from liminal spaces between buildings up to the regional space between cities, interstitial spaces describe different levels of relationality that connect or separate surroundings. As part of their nature, the system of interstitial spaces is far from being static, empty, or inert. Instead, interstitial spaces present a range of attributes that can be analysed through their environmental potentials, spatial attributes, and flexibility to absorb different functions and changes. The interstices increase the porosity of cities and qualify the built environment through their spatial values as in-between land. On this basis, it is argued that interstitial spaces can play a key role in the resilience and adaptation capacities of cities, and improve their condition as climate-responsive environments against the impacts of climate change and natural disasters. Assuming the environmental potential of interstitial spaces, they can also help in combatting the unsuitable character of sprawling growth and consolidate processes of land fragmentation as source of interstitiality.

As demonstrated through the case of Santiago de Chile, the interstices configure a diverse spectrum of land with differing relationalities and environmental services. They suggest new categories of public land with the potential to activate suburban areas, attract wildlife, accumulate rainwater, facilitate risk management during natural disasters, improve the adaptation capacity of local communities, and improve the overall urban resilience. As demonstrated by the case of the orchards and other farming spaces, farming interstices suggest alternative conceptions of rurality, green infrastructure, multifunctionality, natural and cultural heritage, and social resilience. The extraction sites of La Florida, demonstrate the spatial versatility of the interstices as 'ever-changing geographies' that can accommodate new environmental functions and absorb drastic changes triggered by accelerated processes of suburbanisation. The conurbation space of Santiago represents an opportunity to articulate multifunctional land uses beyond binary urban–rural oppositions. Beyond the case of Santiago de Chile, it has been clarified that interstitial spaces define a spatial system in its own right that can be better equipped to absorb environmental shocks while securing urban functionality. This raises further questions around the planning and design challenges associated with the interstitial spaces, and the political meanings associated with the creation of sustainable urban environments through the production of interstices as another mode of the production of the space.

Acknowledgements

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Perceptions of blue-green and grey infrastructure as climate change adaptation strategies for urban water resilience

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Abstract: Blue-Green Infrastructure (BGI, including swales, green roofs, and wetlands) plays an important role in reducing vulnerability to climate change risks such as flooding, heat stress, and water shortages, while enhancing urban environments and quality of life for citizens. Understanding the perceptions that professional stakeholders have of BGI is fundamental in addressing barriers to implementation. A novel application of the Implicit Association Test (IAT) is developed to investigate and compare implicit (unconscious) perceptions of blue-green and grey infrastructure with explicit (conscious) attitudes. This is the first time an IAT about BGI has focused on professional stakeholders. Blue-green and grey infrastructure are perceived positively by the sample population. Overall, respondents implicitly and explicitly prefer BGI to grey infrastructure, and regard it as safer, tidier, more attractive, useful, valuable, and necessary. The individual positive explicit perceptions of grey infrastructure, nonetheless, suggest that integrated blue-green and grey systems may be preferable for professional stakeholders to incorporate into water management and climate change adaptation strategies.

Keywords: Blue-Green Infrastructure, Implicit Association Test, perceptions, grey infrastructure, climate change, adaptation, stakeholders, attitudes, flooding, urban water management.

Notes on the authors: see end of article.

Introduction

Cities around the world face the challenge of adapting to the impacts of climate change, including more frequent and intense rainfall events, droughts, and heatwaves (IPCC 2014, Arnell *et al.* 2016, Guerreiro *et al.* 2018). The sustainable management of water resources is also crucial for urban climate resilience (Özerol *et al.* 2020). The form and function of cities intensifiy climate change impacts (Carter *et al.* 2018): urban development and consequential expansion of hard surfacing, for example, result in the loss of natural blue and green spaces that previously contributed to reducing flood risk through infiltration, attenuation, conveyance, and/or storage (O'Donnell & Thorne 2020). Flooding is a major risk for urban environments: for example, it is the greatest risk to infrastructure in the UK from climate change (Dawson *et al.* 2018). The increase in hydrological extremes seen across the globe as a result of human-induced climate change (Gudmundsson *et al.* 2021) has led to many international cities developing adaptation strategies to reduce the impacts of climate change while maintaining (or enhancing) healthy environments, quality of life for citizens, and economic activity (City of Rotterdam 2013, City of Melbourne 2017, Scottish Government 2019). In the European Union these may include strategies for smart specialisation whereby unique opportunities for development and growth are identified based on assets, resources, and specific socio-economic challenges in different cities, regions, and countries (European Commission 2020), achieving the aim of cohesion policy by promoting a better link between the production of new knowledge stemming from innovation and investment, and its application to new projects and services (D'Adda *et al.* 2020). Climate change adaptation is increasingly framed as an opportunity to improve liveability and well-being in cities (Aylett 2015). Progressively more local governments are including climate resilience within broader goals to improve quality of life in cities (Hölscher *et al.* 2019) and meet the Sustainable Development Goals (SDGs), particularly around good health and well-being (SDG3), clean water and sanitation (SDG6), and sustainable cities and communities (SDG11).

The functionality provided by urban green (and blue) space is increasingly important in a changing climate (Gill *et al.* 2007). Blue-Green Infrastructure (BGI), often referred to in the context of flood and water management, is defined by the use of natural and designed blue and green components to mimic and/or enhance natural hydrological cycle processes of infiltration, evapotranspiration, and reuse (Novotny *et al.* 2010). BGI assets, including swales, rain gardens, green roofs, wetlands, street trees, ponds, and re-naturalised and de-culverted rivers, are designed to turn 'blue' (or 'bluer') during rainfall events in order to reduce urban flood risk. BGI, like Nature-Based Solutions (NBS) and Sustainable Drainage Systems (SuDS), offers a multifunctional approach that can further reduce vulnerability to other climate change risks, such as heat stress, water shortages, and air pollution (Demuzere *et al.* 2014). Despite extensive evidence of the multiple benefits of BGI, and provision of ecosystem services (e.g., Hansen & Pauleit 2014, Fenner 2017, Alves *et al.* 2019a, Paulin *et al.* 2020), a range of institutional, socio-political, and technical barriers limit widespread adoption (Brown & Farrelly 2009, O'Donnell *et al.* 2017).

Understanding the myriad perceptions that professional city stakeholders hold towards different types of BGI in the public realm is fundamental in addressing the socio-political barriers to their implementation and ultimately delivering BGI projects that are accepted, supported, and desired (Suppakittpaisarn *et al.* 2019, O'Donnell *et al.* 2020a). Previous research into the perceptions of BGI has focused on residents and communities living alongside blue-green assets, and typically report stated preferences based on explicit, or self-reported measures such as questionnaires, interviews, and Likert-scale tests (e.g., Hayden *et al.* 2015, Derkzen *et al.* 2017, Wang *et al.* 2017, Everett *et al.* 2018, Williams *et al.* 2019). It is essential to supplement knowledge of public perceptions with an understanding of the attitudes of professionals working with blue-green and grey infrastructure, in order to understand challenges and opportunities, and to identify where changes in research foci, policy, and practice are needed for increased implementation of multifunctional BGI. Furthermore, these experts are trusted to develop BGI projects that deliver multiple benefits beyond urban water management, founded on their perceptions of what constitutes a 'good' design (Suppakittpaisarn *et al.* 2019). The need to understand their preferences, and understand how they may differ from public perceptions, is of paramount importance.

Investigations into the perceptions of blue-green and grey infrastructure held by professional stakeholders, to date, have used explicit measures. As an example, Shandas *et al.* (2019) explored the social, political, and biophysical opportunities and challenges of Green Stormwater Infrastructure (GSI) systems through focus groups with municipal managers in Portland, Oregon, and Clark County, Washington, USA. Miller and Montalto (2019) used a structured online survey to investigate the range of ecosystem services that New York City practitioners attribute to different types of Green Infrastructure (GI), ultimately inferring which types of GI are most desirable to professional stakeholders and why. While designers' and laypeople's preferences for different categories of GSI were found to be similar, Suppakittpaisarn *et al.* (2019) identified significant differences between preferences for bioretention basins and green roofs.

The explicit attitude measures employed in these examples assume that participants know and can articulate their beliefs (Schultz *et al.* 2004) and have an internalised concept of GSI/GI that they consciously base their attitudes on. While we expect professionals working with BGI to be able to articulate their explicit perceptions of blue-green and grey infrastructure, explicit attitude measures are also affected by self-presentation effects—that is, responses that attempt to convey information about oneself or a desired image of oneself to other people (Baumeister & Hutton 1987)—that undermine their validity (Gregg & Klymowsky 2013). Implicit attitude measures that are not consciously controlled (that is, are spontaneous) remove many of the external influences that affect explicit tests (Spence & Townsend 2006), and provide insight into underlying or unspoken attitudes that may diverge from conscious attitudes (Greenwald & Banaji 1995).

The Implicit Association Test (IAT) is widely used to reveal implicit attitudes by measuring the strengths of concept–attribute associations (Greenwald *et al.* 1998). The IAT is a computer-based methodology in which participants sort stimuli into pairings of contrasting target-concepts and evaluative attributes; the response time of different pairings is compared to determine implicit preferences. Participants match stimuli, either words or photographs (for example, Daisy or Caterpillar) with the appropriate concept (for example, Flower or Insect) as quickly as possible. Two concepts are then combined (Flower and Pleasant; Insect and Unpleasant). Implicit attitudes are calculated as the difference between the average response times for compatible trials (Flower and Pleasant; Insect and Unpleasant) and incompatible trials (Flower and Unpleasant; Insect and Pleasant).

Early IATs focused on controversial or sensitive topics, investigating implicit prejudices based on race, religious ethnicity, age, and nationality (e.g., Greenwald *et al.* 1998, Rudman *et al.* 1999). In the field of environmental research, IATs have been used to investigate perceptions of climate change (Beattie & McGuire 2012), nuclear power (Siegrist *et al.* 2006, Truelove *et al.* 2014), implicit connectedness with nature (Schultz *et al.* 2004, Bruni & Schultz 2010, Liu *et al.* 2019), and the influence of extreme weather on voting habits (Rudman *et al.* 2013). Implicit attitudes towards blue-green and grey infrastructure are not yet understood. In a novel application of the IAT, O'Donnell *et al.* (2020a) investigated and compared implicit and explicit perceptions of SuDS in public greenspace, based on a sample population of residents in Newcastle-upon-Tyne, UK (n = 193). Greenspace with and without SuDS were perceived positively by most respondents yet greenspace without SuDS was implicitly and explicitly preferred, and explicitly regarded as more attractive, tidier, and safer.

Study scope and rationale

In this paper, we investigate and compare implicit and explicit perceptions of blue-green and grey infrastructure, measured by an IAT and feeling thermometers,[1] respectively, of professionals with expertise in blue-green and grey infrastructure from a range of disciplinary backgrounds: for example, engineering, environmental management, implementation, landscape architecture and design, planning, and policy. The sample population is drawn from professionals engaging with the research project '*Developing new Blue-Green futures: multifunctional infrastructure to address water challenges*', part of the British Academy programme on Tackling the UK's International Challenges (Blue-Green Futures 2019). This project explores how four international cities, at the forefront of BGI implementation in their respective countries (Newcastle, UK; Rotterdam, The Netherlands; Portland, Oregon, USA; and Ningbo, China), are tackling urban flood and water challenges and developing visions for *Blue-Green urban futures*, characterised by widespread implementation of multifunctional BGI that delivers multiple benefits for the environment, society, and economy (O'Donnell *et al.* 2021). For instance, Rotterdam is an international leader in aligning climate change adaptation, water management, and spatial planning to increase urban resilience to the impacts of climate change, while concurrently improving quality of life (Tillie & van der Heijden 2016). Ningbo is a Chinese pilot city in the 'Sponge City Programme', tasked with integrating low-impact development and BGI with urban planning to mitigate flood risk, manage stormwater, improve water quality, and store water for future use (Jiang *et al.* 2017). Portland has invested widely in BGI over the last two decades to alleviate loadings on the piped infrastructure system, improve water quality, and manage flood risk (McPhillips & Matsler 2018), and has one of the oldest and most successful GI programmes in the United States. Finally, risk management authorities in Newcastle are investing in combinations of blue-green and grey infrastructure to improve the city's resilience to future flooding while delivering social and environmental benefits from above-ground, attractive BGI systems (Amec Foster Wheeler 2016).

This geographically targeted investigation used purposive sampling (Tongco 2007) to select participants in the four cities and provide a breadth of experiences around blue-green and grey infrastructure. As a random sample of professional stakeholders was not taken, the findings are specific to the sample group. Limited sample sizes in each city preclude a comparison of perceptions in Newcastle, Ningbo, Portland, and Rotterdam (O'Donnell *et al.* 2021). Location is one of the many factors that could influence perceptions of BGI, as could awareness of purpose and function

[1] A visual scale that enables respondents to express their attitudes about a given subject by applying a numeric rating of their feelings (referred to as 'slider bars' in the USA).

(Everett *et al.* 2018), broader environmental attitudes around climate change (Schultz *et al.* 2004), demographic factors, and how facilities are used within the public realm (Lamond & Everett 2019). As these factors were not controlled, we rationalise that our data present general insight into perceptions of blue-green and grey infrastructure in the four cities, and recommend further investigation to uncover the influence that the aforementioned factors, including location, have on perceptions of BGI. We expect respondents to express positive explicit perceptions of BGI, owing to the expert knowledge they hold of the benefits of such approaches and their professional role in BGI strategy, planning, design, and implementation. To our knowledge, this is the first comparative study of the implicit and explicit perceptions that professional stakeholders have of blue-green and grey infrastructure, and, hence, presents a novel exploration of whether stated preferences for BGI align with unconscious perceptions. This research also contributes to the urban studies literature by providing the first insight into implicit perceptions of blue-green and grey infrastructure which play a key, but previously unexplored, role in influencing attitudes and behaviours around urban water management.

Methods

Online surveys

The sampling frame was professional stakeholders with expertise in BGI, stormwater management and/or climate change adaptation and mitigation, urban planning, design, and implementation. Participants were drawn from government organisations, private organisations (such as UK water companies or environmental consultancies), academia, and nonprofits (such as environmental charities and advocacy groups). Participants were recruited with a personalised email from the research team, and directed to the online survey. Forty-four participants were invited with 93 per cent (n = 41) completing all questions (fourteen from Newcastle, and nine each from Ningbo, Rotterdam, and Portland). The survey took approximately 10 minutes to complete and was open from July 2019 until January 2020. Four identical surveys were launched: one using UK English, one US English, one in Dutch, and one in Chinese. As the IAT score was determined by response times to different pairings of target-concepts and evaluative attributes, it was imperative that respondents understood the instructions and that the words used were easy to visualise and unambiguously classifiable: hence, the need for four tests.

Participants read a participant information sheet and granted consent prior to completing the survey. Participants were first asked to read a definition of BGI to remove any ambiguities regarding the meaning of BGI in this study: '*Blue-green infrastructure (including swales, rain gardens, green roofs, wetlands, street trees, and ponds) is an approach to stormwater and flood risk management that uses vegetation and soils to enhance and/or mimic the natural hydrological cycle processes of infiltration, evapotranspiration and reuse.*' They then completed the BGI feeling thermometers. Participants were next asked to read a definition of grey infrastructure: '*Traditional grey infrastructure refers to the human-engineered infrastructure used in conventional piped drainage, storage, water treatment and water supply systems. Infrastructure includes storm drains, storage tanks, culverts, subsurface pipes and combined sewer overflows. It typically refers to components of a centralised approach to water management.*' They then completed the grey infrastructure feeling thermometers. Words were used instead of photographs in all tests in order to assess participants' internal understanding of blue-green and grey infrastructure and avoid introducing bias associated with image choice. Finally, participants completed the IAT (detailed subsequently).

Explicit test: feeling thermometer

Participants completed twelve thermometers to assess their feelings towards the safety, attractiveness, tidiness (or, for the US tests, how maintained they are perceived to be, which is more commonly used to describe the appearance of BGI), usefulness, valuableness, and necessity of blue-green and grey infrastructure (Appendix 1). Participants were instructed to click anywhere on the feeling thermometer to activate the slider and then drag the slider to the point that best reflects their feelings for each attribute. Scales ranged from 0 (for example, extremely unsafe) to 100 (extremely safe). As the initial starting position of the slider can influence the score—for example, respondents are more likely to select the slider's default value (Liu & Conrad 2019)—the thermometers were designed without a default value. Clear instructions were given regarding how responses may be registered to reduce the risk of non-response (Roster *et al.* 2015). Averages of the six scores for BGI, and six scores for grey infrastructure, were calculated. Thermometer Difference (TD) scores were then calculated by subtracting the average BGI score from the average grey infrastructure score, and then normalised to a −2 to +2 scale to be consistent with the IAT D-score. Positive TD-scores indicate a preference for BGI, while negative scores reflect a preference for grey infrastructure.

Implicit Association Test (IAT)

The IAT method described by Greenwald *et al.* (1998) was followed and adapted to compare the automatic associations of blue-green and grey infrastructure. The appearance, instruction text, and programming of the new online IATs were based on the FreeIAT software (Meade 2009). Two types of stimuli were used: target-concepts and evaluative attributes. Target-concepts comprised seven words describing common types of BGI, and seven words describing grey infrastructure that are frequently used to manage stormwater (as shown in Table 1). The evaluative attributes consisted of seven positive and seven negative words that were originally selected from an online thesaurus as frequently used English-language synonyms for positive and negative concepts, and align with the attributes tested in the feeling thermometers. Of primary importance was that the words were easy to visualise and unambiguously classifiable as positive or negative; the actual selection of the words were of secondary importance as IAT scores typically reflect attitudes towards the overarching target-concepts rather than attitudes towards the individual exemplars of those concepts (De Houwer 2001). The implicit perceptions of safety, attractiveness, tidiness, usefulness, valuableness, and necessity (the six attributes tested in the feeling thermometers) are not directly assessed by the IAT but influence the resulting score.

Each IAT began with an introduction to the test and instructions for the participants (Appendix 2). The IAT consists of five blocks, each block containing twenty trials whereby each trial is associated with one stimulus, either a target-concept or evaluative attribute word (as shown in Table 2). Stimuli are randomly selected in all tests and then entered back into the selection processes: that is, a word could appear multiple times during one trial block. During the test, the randomly selected stimuli are presented, one at a time, in the centre of the screen and participants are asked to categorise each stimulus as quickly as possible using the left ('e') and right ('i') keys. The categories that the 'e' and 'i' keys represent are listed at the top of the screen, and are different in each block depending on the task description (for example, initial combined task), as illustrated in Table 2, with the solid black circles indicating allocation of the stimulus to either the left ('e') or right ('i') hand responses. For example, in Block 1 (initial target-concept discrimination), the participant would select the 'e' key if the stimulus was a word describing BGI, or the 'i' key if the word described grey infrastructure. Each stimulus is shown on the screen until a correct response (that is, the classification of the stimulus into the pre-selected categories), is registered. If an

Table 1. Words used in the Implicit Association Test (IAT); positive and negative evaluative attribute words, and target-concepts describing Blue-Green Infrastructure (BGI) and Grey infrastructure.

Positive words	Attractive, Clean, Healthy, Reliable, Safe, Useful, Valuable
Negative words	Dangerous, Dirty, Ugly, Unhealthy, Unreliable, Useless, Worthless
Blue-green infrastructure	Green roof, Green wall, Retention pond, Rain garden, Street tree, Swale, Wetland
Grey infrastructure	Combined sewer overflow, Culvert, Sewer, Storm drain, Subsurface pipe, Underground storage tank, Storm sewer

Table 2. Trial blocks in the Implicit Association Test (IAT). A solid black circle indicates allocation of a word to a left ('e') or right ('i') hand response. Modified after Greenwald *et al.* (1998).

Block	1	2	3	4	5
Task description	Initial target-concept discrimination	Evaluative attributes discrimination	Initial combined task	Reversed target-concept discrimination	Reversed combined task
Number of trials	20	20	20	20	20
Task instructions	● Blue-green	● Positive	● Blue-green ● Positive	● Blue-green	Blue-green ● Positive ●
	Grey ●	Negative ●	Grey ● Negative ●	● Grey	● Grey ● Negative
Function	Practice	Practice	Test	Practice	Test

incorrect response is given (for example, by classifying a retention pond as grey infrastructure), a red 'X' appears on the screen and the respondent must select the correct response key for the test to continue.

If participants find one of the combined tasks (blocks 3 or 5) easier (or faster to respond to) than the other, this means that they differentially associate target-concepts with evaluative attributes, which provides a measure of the implicit attitudinal difference among the target-concept categories. The IAT effect (called the 'difference' or D-score) is the difference between the average response time across all trials in block 5 minus the average response time in block 3. D-scores were calculated using the improved scoring algorithm (Greenwald *et al.* 2003) adapted for five blocks rather than the original seven (O'Donnell *et al.* 2020a). D-scores range from −2 to +2. Following standard practice, trials with response times >10000 ms or <300 ms for more than 10 per cent of their trials, were removed (Greenwald *et al.* 2003). The block mean of correct trials + 600 ms was added to trials initially answered incorrectly. A high D-score indicates that BGI was more closely associated with positive concepts and/or less closely associated with negative concepts, than grey infrastructure. D-scores between −0.2 and +0.2 are considered neutral, indicating no preference (Beattie & McGuire 2012).

Results

The mean explicit TD-score was 0.66 (SD = 0.52, n = 41), indicating that the sample population has an explicit preference for BGI (Figure 1; all scores are provided in Appendix 3). TD-scores ranged from −0.36 to 1.55. 78 per cent of the individual respondents expressed an explicit preference for BGI compared with 15 per cent who

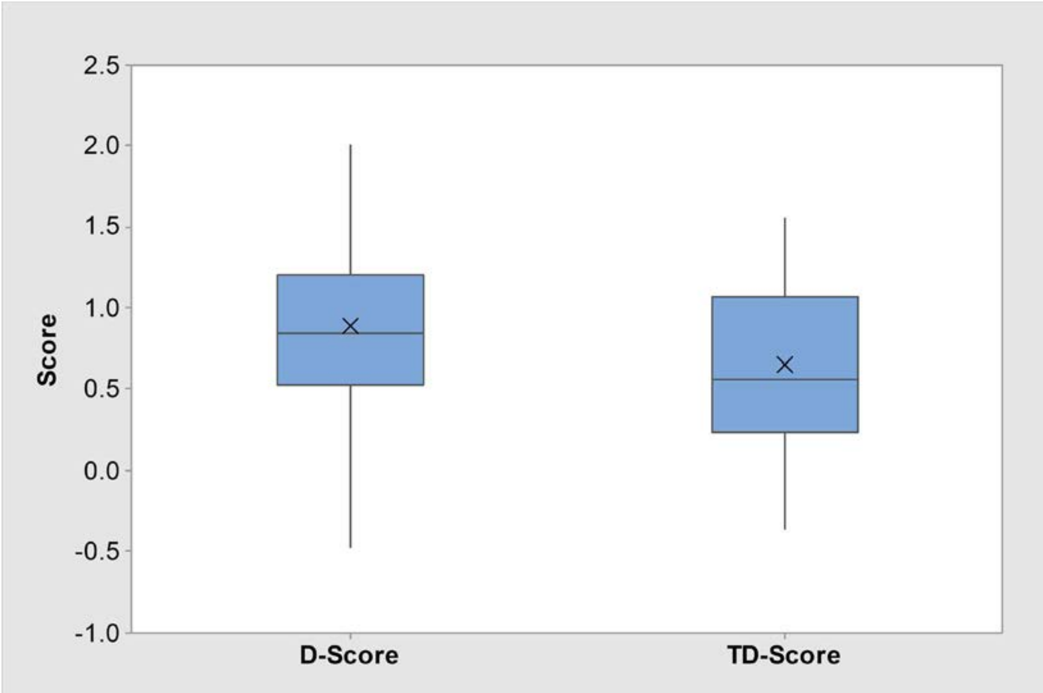

Figure 1. Distributions of D-scores (IAT) and normalised TD-scores (feeling thermometer). The median score is denoted by the centre line, the mean is the cross, the box denotes the Interquartile Range (IQR), and the upper (and lower) whiskers extend to the maximum (and minimum) data point within 1.5 times the IQR.

gave a neutral response and 7 per cent who demonstrated a preference for grey infrastructure (Figure 2). The mean implicit D-score was 0.89 (SD = 0.52, n = 41), indicating a slightly stronger implicit preference for BGI within the sample population (Appendix 4). D-scores ranged from −0.47 to 2.00. 90 per cent of individual responses showed an implicit preference for BGI, compared with 7 per cent who exhibited a neutral response and 2 per cent who showed an implicit preference for grey infrastructure (Figure 2). TD-scores and D-scores exhibited normal distributions (Shapiro–Wilk test, p = 0.299 and p = 0.624, respectively). Statistical analyses were conducted with SPSS 25.0.

A weak but statistically significant correlation was observed between TD-scores and D-scores (r = 0.380, p = 0.014), which is comparable to correlations reported between explicit tests and IATs in earlier research (Hofmann *et al.* 2005, Rudman *et al.* 2013, O'Donnell *et al.* 2020a). This further demonstrates the importance of IATs in research into such environmental attitudes (Schultz *et al.* 2004). Despite this, TD-scores and D-scores were significantly different (t = 1.995, p = 0.049, Independent Samples T-test). Higher variability in TD-scores is demonstrated by the greater

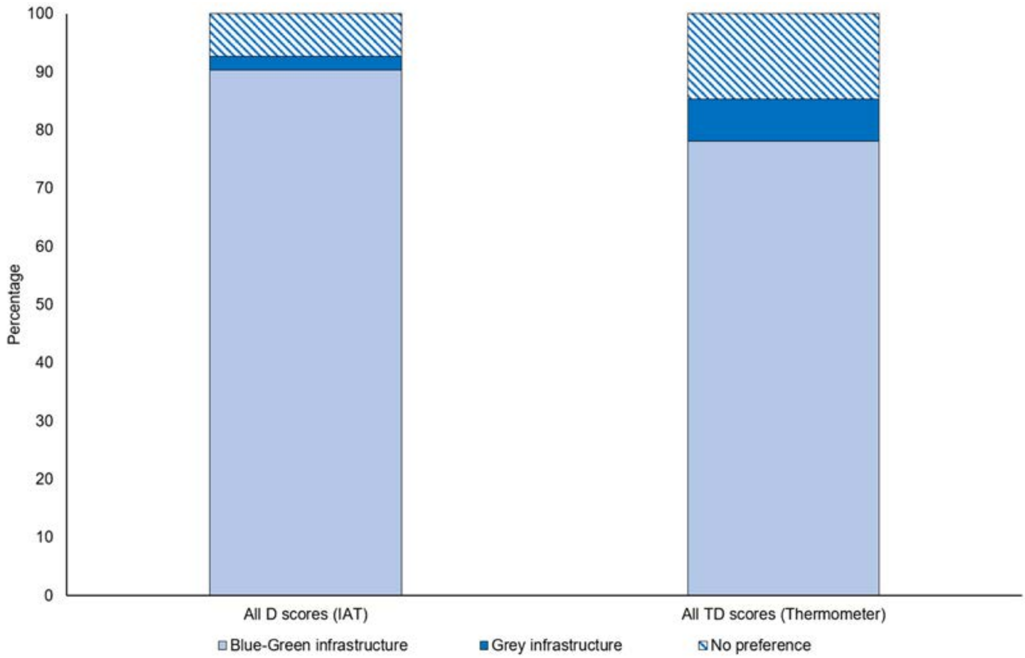

Figure 2. The percentages of respondents who demonstrated a preference for Blue-Green Infrastructure, Grey infrastructure, or no preference, for all data (n = 41), based on the Implicit Association Test (IAT) D-scores and Feeling Thermometer Difference (TD) scores.

interquartile range (IQR; Figure 1) compared with D-scores that clustered more around the mean with some longer whiskers (upper and lower) suggesting several strongly positive and negative individual implicit perceptions.

Explicit characteristics of blue-green and grey infrastructure

The positive average scores in the six feeling thermometer subcategories, excluding attractiveness of grey infrastructure, show that respondents have positive feelings towards blue-green and grey infrastructure (as shown in Table 3 and Figure 3) and regard both types of infrastructure as safe, tidy, useful, valuable, and necessary. However, only BGI was regarded as attractive. Overall, BGI is regarded, in a statistical sense, as significantly safer, more attractive, more useful, more valuable, and of greater necessity than grey infrastructure (Table 3, Independent Samples Mann–Whitney U-tests). BGI is perceived, on average, as tidier than grey infrastructure, although this relationship is not statistically significant.

Despite these overarching trends, the data reveal much variability in perceptions of blue-green and grey infrastructure. Attributes of BGI assessed by the feeling thermometers show greater agreement within the sample population (smaller standard

Table 3. Median scores in the six feeling thermometer subcategories. All scores are normalised to a −2 to 2 scale, standard deviation is given in parentheses and the range in italics. The larger the score, the greater preference for the target variable.

	Safety	Attractiveness	Tidiness[b]	Usefulness	Valuableness	Necessity
Blue-Green	1.60 (0.66)	1.56 (0.60)	0.80 (0.74)	1.80 (0.54)	1.72 (0.49)	1.84 (0.61)
	−0.80 to 2.00	*−0.56 to 2.00*	*−1.70 to 2.00*	*−0.04 to 2.00*	*−0.20 to 2.00*	*−0.16 to 2.00*
Grey	1.16 (0.94)	–0.96 (0.81)	0.68 (0.97)	1.20 (0.78)	1.12 (0.69)	1.20 (0.81)
	−2.00 to 2.00	*−2.00 to 0.72*	*−1.60 to 2.00*	*−1.04 to 2.00*	*−0.80 to 2.00*	*−1.28 to 2.00*
***p*-value[a]**	0.008	0.000	0.133	0.003	0.000	0.016

[a] Significant difference between Blue-Green and Grey scores under each category were assessed using Independent-Samples Mann–Whitney U-tests; significant differences at the $p = 0.05$ level are underlined. Data in all subcategories, excluding 'Tidiness—Blue-Green' and 'Valuable—Grey exhibited non-normal distributions (Shapiro–Wilk test, $p \leq 0.05$).
[b] Tidiness or maintained (US test).

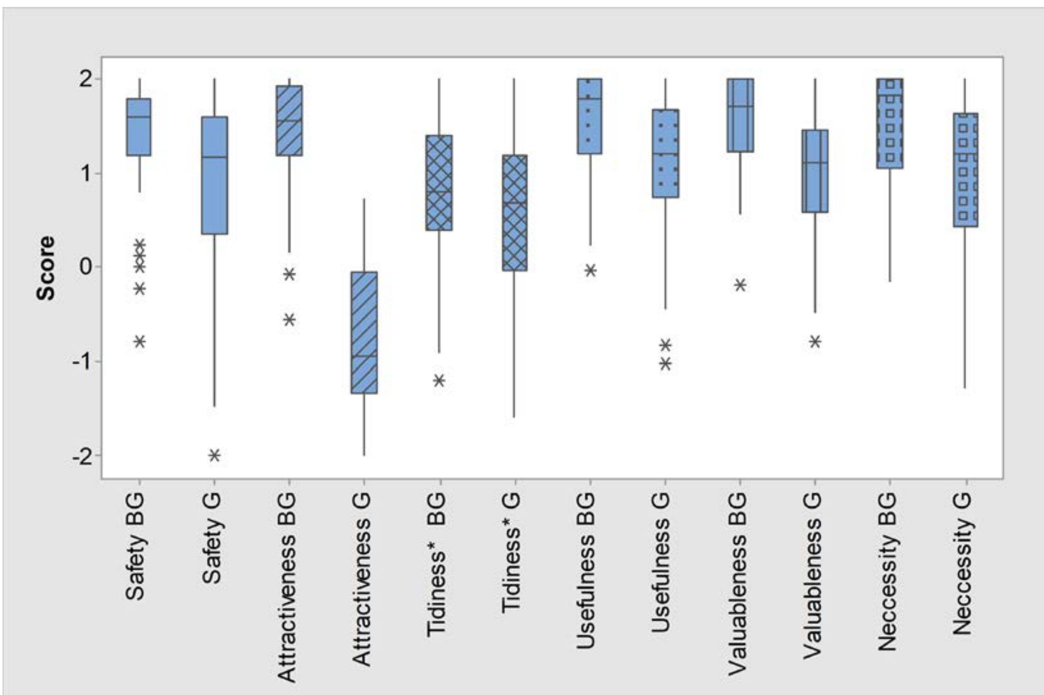

Figure 3. Distributions of feeling thermometer scores for Blue-Green (BG) and Grey (G) infrastructure in the six categories. The median score is denoted by the centre line, the box denotes the Interquartile Range (IQR), and the upper (and lower) whiskers extend to the maximum (and minimum) data point within 1.5 times the IQR. Outliers (starred) are data points beyond the lower whiskers. *tidiness or maintained (US test).

deviations and IQRs) when compared with grey infrastructure where views are more variable (Figure 3). The longer negative whiskers for the grey infrastructure attributes suggest that several respondents feel strongly that grey infrastructure is unsafe, unattractive, untidy, useless, not valuable, and unnecessary. Aside from the unattractiveness of grey infrastructure that is supported by the majority (76 per cent) of respondents, negative perceptions of the other attributes of grey infrastructure typically represent a minority of strong negative preferences within the general population that regard grey infrastructure more favourably, including three respondents with outlier scores (two from Ningbo, one from Portland). With regards to BGI, several respondents hold negative perceptions of BGI attributes, as represented by the negative outliers in Figure 3 for BGI safety (5), attractiveness (2), tidiness (1), usefulness (1), and valuableness (1). The outliers for BGI attributes represent six respondents, all from Ningbo.

Significant positive correlations were observed between several BGI attributes, including attractiveness and tidiness ($r = 0.429$, $p = 0.006$) and safety and usefulness ($r = 0.460$, $p = 0.002$) (Spearman's rank-order correlations, detailed in Appendix 5). The strongest correlations were observed between usefulness and necessity ($r = 0.657$, $p = 0.000$), usefulness and valuableness ($r = 0.610$, $p = 0.000$), and valuableness and necessity ($r = 0.816$, $p = 0.000$). Similarly, the usefulness and valuableness of grey infrastructure were positively correlated ($r = 0.603$, $p = 0.000$), as were usefulness and necessity ($r = 0.456$, $p = 0.003$), valuableness and necessity ($r = 0.495$, $p = 0.001$), and safety and usefulness ($r = 0.567$, $p = 0.000$).

Discussion

Using IATs to assess perceptions of blue-green and grey infrastructure held by professional stakeholders working closely with these infrastructures is a notable advance from tests solely employing explicit measures (Miller & Montalto 2019, Shandas *et al.* 2019, Suppakittpaisarn *et al.* 2019). The data presented in this paper contribute to our growing understanding of the complexity of attitudes towards blue-green and grey infrastructure, and attributes that influence preferences (for example, safety, attractiveness, and necessity), by presenting insight into unconscious perceptions and subsequently comparing those with stated preferences.

Explicit and implicit preferences for blue-green and grey infrastructure

The majority of respondents in the sample population associate BGI more closely with positive concepts (and/or less closely with negative concepts) than grey infrastructure, suggesting an agreement between conscious and subconscious attitudes that BGI is more highly valued than grey infrastructure. Several reasons may provide an explanation. The sample population is expected to be highly knowledgeable about the advantages, disadvantages, benefits, challenges, opportunities, and uncertainties associated with blue-green and grey infrastructure, owing to their current roles and disciplinary expertise in blue-green and grey infrastructure policy, planning, design, engineering, and implementation. Participants may acknowledge the greater multi-functionality of BGI: that is, that BGI delivers a wider range of social, environmental, and economic benefits compared with grey infrastructure (Hansen & Pauleit 2014, Fenner 2017, Alves *et al.* 2019a, Paulin *et al.* 2020). Recognition of the multiple benefits of BGI beyond water treatment and flood control have also been highlighted in focus groups with thirteen professional stakeholders in Portland and Clark County, Washington (Shandas *et al.* 2019), and online surveys with twenty New York City practitioners that showed that groups most familiar with BGI (such as practitioners) typically assign the most value to the ecosystem services that BGI provides (Miller & Montalto 2019).

Respondents may assume that BGI is a more effective use of space and, if designed with multifunctionality in mind, can address local challenges, including flooding, air pollution, urban heat island effects, and biodiversity loss (Connop *et al.* 2016). While the definitions of BGI and grey infrastructure given at the start of the explicit tests referred to their respective roles in flood and water management, additional benefits (for example, environmental enhancement, climate change adaptation, or improvements to health and well-being) were not mentioned to avoid potential response bias. The feeling thermometer instructions asked respondents to state, for example, how useful they feel BGI is; the context of 'usefulness' was not dictated, hence, the meaning was interpreted by the respondents before they gave their score.

BGI could also be perceived as a proxy for nature and greater preference for BGI could imply a higher connectedness with nature, compared with built environments, as observed by Schultz *et al.* (2004). Similarly, it could be that respondents prefer natural over built environments (Kaplan & Kaplan 1989) and the terms 'Blue-Green infrastructure' and 'Grey infrastructure' conjured subconscious and/or conscious images of blue-green and grey systems at much larger spatial scales. Nonetheless, it is beyond the ability of the IAT to explain *why* implicit perceptions are more closely associated with positive concepts than grey infrastructure. Due to the relative nature of the IAT, it is also impossible to discern whether respondents have a positive association with BGI or a negative association with grey infrastructure (or both), which is an important limitation (Siegrist *et al.* 2006). Explanation of attitudes towards blue-green and grey infrastructure are likely to be more nuanced and context specific, which preclude capture by the IAT or feeling thermometers. As one respondent from Portland noted:

> *Grey is not good or bad but needed where it is needed. The difference is a designer's ability to know when and how much grey is needed with green and vice versa.*

Two lines of evidence suggest a slightly stronger implicit (compared with explicit) preference for BGI within the sample population: a higher mean D-score (0.89) compared with the mean TD-score (0.66), and a greater percentage of individual respondents registering a positive score (above neutral) in the IAT compared with the explicit test (90 per cent implicit, 78 per cent explicit, Figure 2). This may be because some of the explicit concerns that respondents have towards BGI are not held in the subconsciousness; respondents are thus expressing more negative feelings than they instinctively feel. Alternatively (or in addition), respondents may rationalise about the advantages and disadvantages of grey infrastructure and decide to highlight positive attributes in the explicit tests; such positive associations may not be part of the internalised concept of grey infrastructure that respondents hold, leading to a stronger implicit (compared with explicit) preference for BGI.

These findings also suggest that social desirability bias, which would have increased the positive explicit scores given to BGI as part of an embedded response of 'liking' all greenspace, was not an important issue. Additionally, the design of the explicit tests, and particularly the attributes used in the feeling thermometers, allowed respondents to rationalise the advantages and disadvantages of grey infrastructure (for example, valuableness vs. attractiveness), which may have resulted in more negative and neutral views overall. Respondents may also have rationalised about the limitations of BGI, including the limited functionality when its design capacity is exceeded, which may be perceived as likely during extreme rainfall events now and in the future (Kabisch *et al.* 2016). This may have influenced the perceptions of usefulness and necessity of BGI approaches. The automatic or spontaneous nature of implicit attitudes, not available through introspection but revealed through the computerised reaction time IAT (Beattie and McGuire 2012), negates such deliberative behaviour (Nosek *et al.* 2002, Hofmann *et al.* 2005).

Variability in responses was evident, suggesting that some professional stakeholders within the sample population do have stronger implicit and explicit attitudes towards blue-green and/or grey infrastructure (D-scores ranged from −0.47 to 2.00 and TD-scores ranged from −0.36 to 1.55). This is further illustrated by the wide range of scores for the individual feeling thermometers measuring the six selected attributes of blue-green and grey infrastructure (as shown in Table 3 and Figure 3), and will be explored in the next section.

Perceptions of attractiveness, tidiness, safety usefulness, valuableness, and necessity

Overall, there was consistency in the positive explicit perceptions of the safeness, tidiness, usefulness, valuableness, and necessity of blue-green and grey infrastructure. Unsurprisingly, respondents found BGI significantly more attractive than grey infrastructure, although 15 per cent of respondents scored grey infrastructure positively, suggesting some appreciation of the aesthetics of this approach. Aside from attractiveness, the negative scores for safety, tidiness, usefulness, valuableness, and necessity of grey infrastructure typically represent a minority of strong negative preferences within the general sample population that regard grey infrastructure more favourably. Outlier scores from three respondents demonstrate strong individual feelings that grey infrastructure is highly unsafe, useless, and not valuable. Similarly, several respondents also hold negative perceptions of BGI safety, attractiveness, tidiness, and valuableness, yet this is a small, outlying minority and should not unduly influence decision making around blue-green and grey infrastructure. However, the fact that the negative outliers for BGI attributes were recorded by six (out of a total of nine) respondents from Ningbo suggest that contextual factors may be influencing explicit perceptions. As five out of the ten negative outliers for BGI attributes refer to safety, there appears to be concerns within Ningbo respondents that BGI is not safe. This requires further investigation as, to our knowledge, there are no further investigations of professional Chinese stakeholder perceptions of the safety of BGI. Concerns around the safety of green roofs were raised by public respondents in Shandong province, China (Wang *et al.* 2017), but we cannot infer whether this reflects the views of Chinese stakeholders in general, or the specific Shandong public sample population.

The lower scores for BGI tidiness reflect the ongoing debate regarding a preference for 'messy' or 'tidy' nature; certain plant species used in BGI (for example, *Juncus* rushes) may be mistaken by some stakeholders for overgrown grasses and weeds and perceived as less aesthetically pleasing (Everett *et al.* 2018), whereas other stakeholders may regard 'messy' BGI as more aligned with natural environments (Tyrväinen *et al.* 2003) and, hence, desirable in urban contexts. The significant positive correlation between scores for attractiveness and tidiness suggests that 'tidy BGI' would be regarded as even more attractive within the sample population. This correlation was also observed in an earlier analysis of resident's perceptions of SuDS (O'Donnell *et al.* 2020a), showing agreement between explicit perceptions of residents and professional stakeholders regarding BGI aesthetics.

The lower scores for the safety of grey infrastructure may be due to some respondents perceiving greater consequences of grey infrastructure failure, which, historically, has seldom been designed to be 'safe-to-fail' (Dong *et al.* 2017) and can potentially induce catastrophic impacts (for example, floodwall collapse)

(Debele *et al.* 2019). Grey infrastructure, like BGI, is designed for a range of different events: for example, urban highway drainage systems in China are designed to manage pluvial flood risk for 1:1 to 1:10 year events (Ministry of Housing and Urban–Rural Development 2016). However, unlike BGI, grey infrastructure is also used to manage coastal and fluvial flood risk associated with high magnitude events: for example, the Rotterdam dyke rings are designed for between 1:4,000 and 1:10,000 year events (City of Rotterdam 2013).While the definition of grey infrastructure that was provided at the start of the explicit test referred to '*the human-engineered infrastructure used in conventional piped drainage, storage, water treatment and water supply systems*', and gave examples of '*storm drains, storage tanks, culverts, subsurface pipes and combined sewer overflows*', it is possible that respondents had an entrenched concept of grey infrastructure that included larger scale assets, which subsequently influenced their responses. The design standards of BGI systems vary by scheme and by city: for example, most urban BGI in the Chinese Sponge Cities are designed to drain runoff from up to 1:30 year rainfall events (Chan *et al.* 2018), whereas the design standard for most UK SuDS is 1:30 years as a minimum (Woods Ballard *et al.* 2015). Consequentially, the risks associated with rainfall events exceeding the design standards of BGI are lower; if exceedance pathways are included, then BGI can be designed to provide some flood reduction benefit when its design capacity is exceeded (Digman *et al.* 2014).

Most respondents regard BGI as significantly safer, more useful, more valuable, and of greater necessity than grey infrastructure, which suggests a widespread acknowledgement of the functionality (or multifunctionality) of BGI and benefits beyond aesthetics. BGI could be perceived as more useful and valuable due to concurrent delivery of multiple environmental and social benefits in addition to the intended benefit to, typically, flood and water management, as discussed in the preceding paragraph. BGI may be perceived as of greater necessity when compared with grey infrastructure due to its ability to reduce vulnerability to other climate change risks beyond flooding, such as heat stress, water shortages, and air pollution (Demuzere *et al.* 2014). Both Rotterdam and Portland have developed strategies to address climate change—for example, the Rotterdam Climate Change Adaptation Strategy (City of Rotterdam 2013) and Portland's Climate Action Plan (City of Portland and Multnomah County 2016)—and, hence, the necessity of BGI to address multiple components of these strategies may have been in the consciousness of the respondents. Likewise, Policy CS16 (Climate Change) in the *Core Strategy and Urban Core Plan for Gateshead and Newcastle upon Tyne 2010–2030* (UK) refers to development providing resilience to the ongoing and predicted impacts of climate change through appropriate location, design, and landscaping (Newcastle City Council and Gateshead Council 2015). Existing grey pipe systems designed to manage urban water have reduced the ability to modify system performance in light of future, uncertain, changes in climate and may also lead to technical lock-in (Ashley *et al.* 2020, Kapetas & Fenner 2020), which may further reduce the perception of usefulness, valuableness, and necessity. In contrast, BGI is acknowledged for its greater adaptability and higher system sustainability under uncertain futures (Dong *et al.* 2017).

The significant positive correlations between usefulness, valuableness, and necessity of BGI and grey infrastructure could imply a similar interpretation of the meaning of the three attributes, and, hence, using all three may be redundant in future studies. In this investigation, TD-scores were calculated by subtracting the average BGI score from the average grey infrastructure score, using an average of the scores for the six attributes. Excluding valuableness and usefulness, and calculating the average BGI and grey scores based on values given for safety, attractiveness, tidiness, and necessity only, did not affect the TD-score (Appendix 6). Interestingly, if attractiveness scores are removed from the TD-score calculation, the TD-score is reduced by 50 per cent (from 0.66 to 0.33, Appendix 6). This implies that attractiveness is a key influential factor in positive perceptions of BGI, and, if attractiveness was not assessed, the preference for blue-green compared with grey infrastructure would be weaker and approaching neutral (0.2).

Integrated systems of blue-green-grey infrastructure

Although most respondents in the sample population associate BGI more closely with positive concepts (and/or less closely with negative concepts) than grey infrastructure, the majority of individual positive explicit perceptions of the safeness, tidiness, usefulness, valuableness, and necessity of blue-green and grey infrastructure suggest that both infrastructure types are valued by the sample population, albeit, with regards to grey infrastructure, on an explicit level only. From this we can infer that integrated systems of blue-green and grey infrastructure may be a preferable strategy in managing urban water and mitigating the impacts of climate change, in addition to delivering benefits to the environment, society, and economy. There is a growing body of evidence that resilience against future environmental threats cannot be achieved by traditional grey infrastructure systems alone, and combinations of blue-green and grey infrastructure can enhance system performance and maximise climate adaptation in cities (Dong *et al.* 2017, Alves *et al.* 2019b, Browder *et al.* 2019, Debele *et al.* 2019, Frantzeskaki *et al.* 2019, O'Donnell *et al.* 2020b, Kapetas & Fenner 2020). The use of traditional buried pipe networks to address, for example, future water challenges associated with climate change and increased urbanisation, is likely to be unaffordable, miss wider opportunities that integrated blue-green and grey approaches could deliver (Dolman & Ogunyoye 2018, Ashley *et al.* 2020), and potentially lead to overdesigned solutions or inadequate system extensions that fail to provide the required additional capacity (O'Donnell & Thorne 2020). BGI and Nature-Based Solutions (NBS) are typically more cost effective than hard engineering approaches used within existing systems, particularly when wider co-benefits are quantified and, where possible, monetised (Braden & Ando 2011, Ando & Netusil 2018, Debele *et al.* 2019).

Taking the projected increase in frequency and intensity of rainfall events as an example (IPCC 2014), the potential integration of blue-green and grey infrastructure to manage urban rainfall can be viewed through four domains, with different combinations of blue-green–grey assets needed to deliver maximum benefit in urban areas: 1) urban resource (everyday rainfall); 2) urban drainage (design rainfall); 3) exceedance design (exceedance rainfall); and 4) flooding domain (extreme rainfall) (Fratini *et al.* 2012, Ashley *et al.* 2020). Combined systems of blue-green–grey infrastructure can manage pluvial flood risk in all domains. In Domain 1, BGI should play a key role in managing smaller rainfall events, which are within the design standard of most assets, and is typically included at an urban planning stage to manage low levels of risk while contributing to quality of place. At the other end of the scale (Domain 4), the impacts of extreme rainfall events can be minimised through effective emergency response measures (including evacuation) and provision of floodable areas. This could include BGI assets such as playing fields, parks ,and open greenspace, in addition to grey infrastructure assets specifically designed to reduce pluvial flood risk, such as the Benthemplein water square in Rotterdam, which manages rainwater while redeveloping the urban environment (Hölscher *et al.* 2019), or designated as floodable, such as car parks. The optimum mix is highly dependent on local conditions (Dong *et al.* 2017, Kapetas & Fenner 2020).

An integrated blue-green–grey approach increases the complexity of options and delivery, moving from a mono-solution problem when grey infrastructure is the sole consideration (Ashley *et al.* 2020) to a multifaced challenge involving a range of public and private stakeholders from different disciplinary standpoints, and consideration of multiple co-benefits beyond water and flood risk management. Nonetheless, integrated blue-green–grey approaches are recommended to help cities progress towards the Sustainable Development Goals (SDGs), particularly around good health and well-being (SDG3), clean water and sanitation (SDG6), and sustainable cities and communities (SDG11). An adaptation pathways approach can reduce this complexity and allow incremental investment in infrastructure to meet future performance requirements while maintaining cost-effectiveness and multiple benefit provision (Kapetas & Fenner 2020). Using a residential case study in a London Borough, Kapetas and Fenner (2020) show that combining BGI interventions (storage pond, bioretention cells, and permeable paving) with the existing grey infrastructure system can more effectively manage future flood risk and maximise other co-benefits (for example, amenity, carbon sequestration, and groundwater recharge opportunities), when compared with grey infrastructure expansion alone. Determining the importance of each benefit at the start of spatial development strategy planning is recommended; not all benefits can be optimised simultaneously and trade-offs will need to be made regarding which risks are to be minimised (Caparros-Midwood *et al.* 2019). For instance, if a blue-green–grey strategy driven by flood risk management objectives achieves the highest total benefit, but compromises flood damage reduction, such a trade-off may not be acceptable to the stakeholders involved (Alves *et al.* 2019b). Smart Specialisation Strategy, to achieve the objectives of cohesion policy, may be drawn upon to enable regional authorities to identify technological domains to concentrate investment and innovation (D'Adda *et al.* 2020), in this case focusing on innovative systems of integrated blue-green–grey infrastructure.

Limitations and directions for future research

The IAT is widely used to reveal implicit attitudes through the strength of concept–attribute associations. Limitations of this method, including the inability to discern whether respondents have a positive association with one target-concept and/or a negative association with the other, were discussed in earlier literature (e.g., Greenwald *et al.* 1998, Rudman *et al.* 1999, Siegrist *et al.* 2006, Gregg & Klymowsky 2013). The logistical challenges, namely the need for a computer to complete the test, are less relevant in current society, and particularly in the professional stakeholder sampling frame used in this study. Still, variations in internet speeds, computer specifications, and distractions may have affected the response times when respondents completed the online IAT, influencing the resultant implicit score. The software is designed to minimise this potential issue: for example, by training respondents first in the two trial runs before the initial combined task (Table 2) and by eliminating responses that exceeded 10,000 ms. Nonetheless, it is accepted that the degree of variability and noise may be larger with implicit attitude measures, when compared with explicit measures (Schultz *et al.* 2004).

Designing the feeling thermometers without a default value is expected to have limited any bias associated with the slider starting position (Liu & Conrad 2019), and thus recorded a representative indication of how the respondents feel towards the six attributes tested. The explicit test score (Thermometer Difference or TD-score), however, is dependent on the attributes used in the feeling thermometers, and it is possible that using different words would have resulted in different scores. This could have resulted in greater explicit preference for BGI (compared with implicit), or even an explicit preference for grey infrastructure. TD-scores calculated using values given for safety, attractiveness, tidiness, and necessity (so excluding valuableness and usefulness) did not affect the TD-score, but removing attractiveness from the TD-score calculation reduced the TD-score by 50 per cent (Appendix 6). The selection of attributes in the explicit tests, and the degree to which the explicit measure is directly or indirectly related to the representation assessed in the IAT, are of paramount importance and influence the degree to which explicit and implicit scores can be compared (Hofmann *et al.* 2005).

The IATs and feeling thermometer tests are unable to explain why certain attitudes and preferences are held within the sample population. Future research could build on this study by explicitly asking respondents why they perceive (or do not perceive) blue-green and grey infrastructure as attractive, safe, tidy or well-maintained, useful, valuable, and necessary, and exploring their feelings towards integrated systems of blue-green–grey infrastructure to address climate change adaptation objectives. Further research could explore more applied questions: for example, investigating whether experience of flood events influences implicit perceptions of blue-green and grey infrastructure, as direct experience with extreme weather events is acknowledged as an effective catalyst for changing implicit attitudes (Rudman *et al.* 2013). Collecting data from a larger sample population in each of the four cities, which would have permitted a comparison of perceptions in Newcastle, Ningbo, Portland, and Rotterdam, and an investigation into whether location and associated governance characteristics could influence implicit perceptions of BGI, may not be possible due to the limited population (in each city) of professional stakeholders working with BGI. However, this should be investigated in future research. Additionally, evaluating whether broader environmental attitudes around climate change influence perceptions of blue-green and grey infrastructure could also develop insight into why certain perceptions are held.

Conclusion

Blue-Green Infrastructure (BGI) is increasingly acknowledged as a strategy to reduce the impacts of climate change in urban environments and reduce vulnerability to risks such as flooding, heat stress, and water shortages, while delivering a range of additional co-benefits to the environment and society. Through the development of a novel application of the Implicit Association Test (IAT), this study investigated the perceptions of BGI held by professional stakeholders in four cities with leading BGI programmes and aspirations (Newcastle, UK; Rotterdam, Netherlands; Portland, Oregon USA; and Ningbo, China). This is the first time an IAT about BGI has focused on professional stakeholders, and the first comparative study of the implicit and explicit perceptions that professional stakeholders have of blue-green and grey infrastructure, and, hence, presents a novel exploration of whether stated preferences for BGI align with unconscious perceptions. It is also the first study to explore professional stakeholders' explicit perceptions of the attractiveness, tidiness, safety usefulness, valuableness, and necessity of blue-green and grey infrastructure. The IAT contributes additional insight into underlying attitudes that are more entrenched in respondents' value systems and cannot be captured by explicit tests, by removing many of the external influences and self-presentation effects (for example, social desirability bias) that affect explicit tests. Implicit attitudes have been little studied in the flood and water management discipline, yet may play a key role in influencing overarching attitudes towards BGI, and improving our understanding of potential disconnects between positive attitudes towards blue-green spaces and behaviours around them (O'Donnell *et al.* 2020a).

Blue-green and grey infrastructure are perceived positively by the sample population, suggesting that they are valued components of landscapes, albeit for different reasons. Stated preferences therefore align with automatic preferences assessed by the IAT. Overall, respondents implicitly and explicitly prefer BGI, and regard it as safer, tidier, more attractive, useful, valuable, and necessary. This suggests a widespread acknowledgement of the functionality (or multifunctionality) of BGI and benefits beyond aesthetic value. As an example, BGI may be regarded as of greater necessity when compared with grey infrastructure due to its ability to reduce vulnerability to other climate change risks beyond flooding, such as heat stress and water shortages. We can infer by the positive perceptions of BGI expressed by the professional stakeholders in this study that their personal perceptions are not barriers to implementation of BGI in their respective cities, as previously assumed (O'Donnell *et al.* 2017, Shandas *et al.* 2019), and other technical and socio-political factors are slowing down BGI progress. However, concerns over the safety of BGI expressed by 50 per cent of the Ningbo respondents may be a barrier to future implementation of blue-green systems. The individual positive explicit perceptions of grey infrastructure, nonetheless, suggest that integrated blue-green and grey systems may be preferable for professional stakeholders to incorporate into urban water management and climate change adaptation strategies. This is based on inferred experts' perceptions that resilience against future environmental threats cannot be achieved by traditional grey infrastructure systems alone, and that combinations of blue-green and grey infrastructure can improve system performance, increase urban climate adaptation, and further enhance urban environments and quality of life for citizens. Exploring implicit perceptions of integrated systems of blue-green–grey infrastructure designed to address climate change adaptation objectives is an important direction for future research.

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Appendices

Appendix 1
Feeling thermometers investigating how safe, attractive, tidy (or maintained in the US version), useful, valuable, and necessary respondents believe blue-green infrastructure is.

N.B. The same six feeling thermometers were used to investigate explicit perceptions of grey infrastructure, substituting 'blue-green' with 'grey' infrastructure.

Please indicate on the feeling thermometers how 1) safe, 2) attractive, 3) tidy, 4) useful, 5) valuable and 6) necessary you feel blue-green infrastructure is. Please click anywhere on the feeling thermometer to activate the slider, and then drag the slider to the point that best reflects your feelings.

1. Please indicate on the feeling thermometer how safe you feel blue-green infrastructure is.

0 20 40 60 80 100
Unsafe Safe

○ Prefer not to answer

2. Please indicate on the feeling thermometer how attractive you feel blue-green infrastructure is.

0 20 40 60 80 100
Unattractive Attractive

○ Prefer not to answer

3. Please indicate on the feeling thermometer how tidy you feel blue-green infrastructure is.

0 20 40 60 80 100
Untidy/unmaintained Tidy/maintained

○ Prefer not to answer

4. Please indicate on the feeling thermometer how useful you feel blue-green infrastructure is.

0 20 40 60 80 100
Useless Useful

○ Prefer not to answer

5. Please indicate on the feeling thermometer how valuable you feel blue-green infrastructure is.

0	20	40	60	80	100
Not valuable					Valuable

○ Prefer not to answer

6. Please indicate on the feeling thermometer how necessary you feel blue-green infrastructure is for flood risk and stormwater management:

0	20	40	60	80	100
Unnecessary					Necessary

○ Prefer not to answer

Appendix 2
Implicit Association Test (IAT): blue-green vs. grey infrastructure

Information presented to respondents prior to competing the IAT, followed by the stages of the IAT, and an example where the IAT score is presented and explained.

You will be presented with sets of words to classify into groups using the 'E' and 'I' keys on the keyboard.

Positive words	Attractive, Clean, Healthy, Reliable, Safe, Useful, Valuable
Negative words	Dangerous, Dirty, Ugly, Unhealthy, Unreliable, Useless, Worthless
Blue-green infrastructure	Green roof, Green wall, Retention pond, Rain garden, Street tree, Swale, Wetland
Grey infrastructure	Combined sewer overflow, Culvert, Sewer, Storm drain, Subsurface pipe, Underground storage tank, Storm sewer

Tips for completing the IAT:

- Two labels at the top will tell you which words or images go with each key.
- Keep your index fingers on the 'E' and 'I' keys to enable rapid response.
- Each word has a correct classification. If you classify the word incorrectly a red 'X' will appear and you will need to press the correct key to move on.
- The test uses response times so please try to respond as fast as possible.

IAT stage 1

Blue-green	Grey

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- Words or images representing the categories at the top will appear one-by-one in the middle of the screen.
- When the item belongs to the category on the left, press the **E** key; when the item belongs to the category on the right, press the **I** key.
- Items belong to only one category.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 1**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 2

Positive words	Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 2**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 3

Blue-green or Positive words	Grey or Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 3**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

IAT stage 4

Grey | Blue-green

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 4**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.

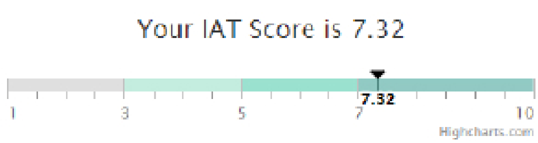
IAT stage 5

Grey
or
Positive words | Blue-green
or
Negative words

- Keep your index fingers on the **E** and **I** keys of your keyboard.
- If you make an error, an **X** will appear. Fix the error by hitting the other key.

Press the **space bar** to begin **Stage 5**.

If the **E** and **I** keys do not work, click the mouse inside the white box and try again.



Your IAT score suggests that you have a preference for *Blue-green infrastructure.*

Information on Implicit Association Tests

The IAT software automatically calculates your implicit (subconscious) preference for blue-green or grey drainage infrastructure based on the speed of your response to the IAT questions and pairing of blue-green or grey, and positive or negative, words. Pairings with faster responses and fewer errors are interpreted as more strongly associated in memory than more difficult pairings (slower responses).

We are interested in comparing your implicit preference with your explicit preference. We can determine this from your responses to the slider bars. Unfortunately, we are not able to report your explicit preferences in real time as the scores need to be calculated off-line. However, we will email your explicit preference to you once this has been calculated.

The spontaneous nature of implicit association tests removes many of the external influences associated with measuring explicit attitudes, and negates issues of social desirability bias, self-enhancement bias, and self-ignorance bias common with explicit tests. IATs have been used to investigate a range of attitudes, including nuclear power (e.g. Truelove et al., 2014) and climate change (Beattie and McGuire, 2012), carbon footprint products (Beattie and Sale, 2009), connections with nature (Bruni and Schultz, 2010), GM foods (Spence and Townsend, 2006) and racial prejudices (e.g. Greenwald et al., 1998).

For more information on the Blue-Green Futures project please see our project blog or contact one of the project team:
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Appendix 3

Individual respondent scores in the Feeling Thermometer tests.

TD = Thermometer Difference, BG = Blue-Green, G = Grey, Ne = Newcastle, P = Portland, R = Rotterdam, N = Ningbo.

Thermometer scores have been normalised to a −2 to +2 scale to be consistent with the IAT D-score.

City	Feeling thermometer scores												
	TD score	Safety BG	Safety G	Attractiveness BG	Attractiveness G	Tidiness BG	Tidiness G	Usefulness BG	Usefulness G	Valuableness BG	Valuableness G	Necessity BG	Necessity G
Ne	0.56	1.20	1.40	1.60	−1.20	1.40	1.60	1.80	1.20	1.36	1.40	1.80	1.40
Ne	−0.08	2.00	2.00	1.52	0.40	0.36	2.00	2.00	2.00	2.00	2.00	2.00	1.96
Ne	0.89	1.80	1.28	1.88	−0.16	1.64	−0.04	2.00	1.80	1.56	1.12	2.00	1.56
Ne	1.55	1.56	1.08	1.64	−1.20	1.12	−1.40	2.00	−0.32	2.00	1.24	2.00	−0.44
Ne	0.69	2.00	2.00	1.80	−1.20	1.80	1.64	1.76	1.60	2.00	1.20	1.24	1.20
Ne	0.95	1.92	1.16	2.00	−1.68	0.68	1.16	2.00	1.16	2.00	1.12	2.00	2.00
Ne	0.45	1.24	1.16	1.20	−1.20	0.44	0.76	1.60	1.16	1.24	0.72	0.84	1.24
Ne	0.55	2.00	1.60	2.00	−0.12	1.60	1.16	1.60	1.64	2.00	1.64	2.00	2.00
Ne	0.41	1.64	1.08	2.00	−1.28	0.48	0.68	1.28	1.72	1.48	1.68	1.16	1.68
Ne	−0.23	1.64	1.96	0.36	−0.48	0.32	1.96	1.96	2.00	1.84	2.00	1.96	2.00
Ne	1.55	1.92	0.72	2.00	0.32	1.84	0.32	2.00	−0.44	2.00	−0.48	2.00	2.00
Ne	1.09	1.32	1.76	1.84	−1.88	0.48	0.16	2.00	1.52	2.00	0.80	2.00	0.72
Ne	0.92	1.80	1.44	1.40	−0.60	1.40	0.08	2.00	1.60	1.44	0.88	2.00	1.12
Ne	0.27	1.20	2.00	2.00	0.00	2.00	1.60	2.00	2.00	2.00	2.00	2.00	2.00
P	1.33	1.76	1.28	1.44	−2.00	0.44	1.00	2.00	0.56	2.00	0.40	2.00	0.40
P	1.40	1.72	−0.08	1.40	−1.32	0.24	0.80	2.00	1.00	1.72	0.08	1.84	−1.00
P	−0.06	1.16	0.32	0.72	−0.12	−0.92	1.16	0.76	2.00	1.56	1.20	2.00	1.08
P	0.19	2.00	2.00	1.16	−2.00	−0.44	0.40	0.80	2.00	1.16	1.16	0.40	0.36
P	1.29	2.00	1.12	2.00	−2.00	0.68	0.36	2.00	1.08	2.00	0.36	2.00	2.00
P	1.13	1.80	−0.44	1.56	−1.92	1.48	1.20	2.00	−0.84	2.00	−0.80	2.00	−1.28
P	1.04	2.00	1.12	1.16	−1.28	0.80	1.24	2.00	1.16	2.00	1.12	2.00	0.36
P	0.20	1.60	1.60	1.64	0.72	1.16	1.68	2.00	1.60	2.00	1.64	1.64	1.60
P	1.47	1.56	0.40	2.00	−0.80	0.64	0.36	2.00	0.72	2.00	−0.44	2.00	1.16
R	0.79	1.72	1.60	2.00	−1.24	0.80	1.20	2.00	2.00	2.00	0.60	2.00	1.60
R	0.63	1.64	1.56	1.16	−1.52	0.00	0.72	1.20	0.76	1.24	0.72	1.16	0.36
R	0.53	1.60	0.88	1.56	−0.12	1.00	0.32	1.08	1.16	1.24	0.76	0.88	1.16
R	0.21	1.12	0.32	0.76	−0.12	0.36	0.36	0.72	1.16	1.12	1.16	1.16	1.12

City	Feeling thermometer scores												
	TD score	Safety BG	Safety G	Attractiveness BG	Attractiveness G	Tidiness BG	Tidiness G	Usefulness BG	Usefulness G	Valuableness BG	Valuableness G	Necessity BG	Necessity G
R	0.14	1.64	1.56	1.44	0.68			1.48	1.92	1.52	1.48	1.76	1.52
R	0.16	1.60	1.12	2.00	0.32	−0.04	1.16	1.16	1.16	1.16	1.12	1.12	1.16
R	0.37	0.24	1.28	1.64	0.24	0.92	−0.12	1.36	1.28	1.20	1.00	0.88	0.32
R	0.97	1.16	−0.08	1.20	0.00	0.36	1.12	2.00	0.40	2.00	0.32	2.00	1.16
R	−0.23	0.00	0.80	1.00	−0.80	−1.20	1.60	1.20	1.20	1.60	0.40	0.40	1.20
N	0.48	0.12	1.60	1.68	−1.64	1.64	−1.60	−0.04	1.32	1.20	1.52	1.00	1.52
N	0.92	1.04	−0.68	1.40	−0.60	0.84	−0.92	2.00	1.44	1.20	1.44	1.16	1.44
N	1.42	1.64	−0.16	1.48	0.16	1.32	−1.04	0.68	0.52	1.88	0.56	1.88	0.32
N	0.29	0.80	1.72	1.96	−1.04	2.00	−1.12	1.24	2.00	0.56	2.00	0.72	2.00
N	0.56	−0.24	0.00	−0.08	−1.36	0.64	−0.56	1.00	0.88	1.76	1.36	1.04	0.44
N	1.41	1.60	−1.48	1.52	−2.00	1.28	−1.56	1.64	1.20	2.00	1.08	2.00	1.20
N	0.70	1.32	−2.00	1.76	−0.96	1.20	0.00	1.40	−0.08	0.68	−0.20	1.08	0.00
N	0.49	2.00	2.00	0.16	−1.32	1.96	−0.68	2.00	−1.04	−0.20	2.00	−0.16	1.84
N	−0.36	−0.80	0.72	−0.56	0.00	0.48	0.68	0.24	0.16	1.00	0.68	0.16	0.44

Appendix 4
Individual respondent scores in the Implicit Association Test (IAT).

City	IAT D-score
Newcastle	0.44
Newcastle	0.14
Newcastle	0.70
Newcastle	2.00
Newcastle	0.54
Newcastle	1.04
Newcastle	0.20
Newcastle	0.52
Newcastle	0.31
Newcastle	0.56
Newcastle	2.00
Newcastle	1.31
Newcastle	1.99
Newcastle	0.78
Portland	1.10
Portland	1.52
Portland	0.90
Portland	1.57
Portland	0.84
Portland	1.40
Portland	1.22
Portland	−0.47
Portland	1.15
Rotterdam	0.20
Rotterdam	0.87
Rotterdam	0.62
Rotterdam	1.02
Rotterdam	1.49
Rotterdam	1.09
Rotterdam	1.07
Rotterdam	1.16
Rotterdam	1.18
Ningbo	0.47
Ningbo	0.48
Ningbo	0.53
Ningbo	0.27
Ningbo	1.26
Ningbo	0.75
Ningbo	0.80
Ningbo	0.74
Ningbo	0.84

Appendix 5
Correlations between explicit attributes of Blue-Green Infrastructure (BGI) and Grey Infrastructure (feeling thermometer data).

A Spearman's rank-order correlation was run to determine the relationships between the six attributes of BGI, and six attributes of grey infrastructure. Shaded cells represent correlations that are significant at the 0.05 level (2-tailed).

BGI

	Safety	Attractiveness	Tidiness	Usefulness	Valuableness	Necessity
Safety		*r* = 0.154 *p* = 0.669	*r* = 0.145 *p* = 0.372	*r* = 0.460 *p* = 0.002	*r* = 0.390 *p* = 0.012	*r* = 0.410 *p* = 0.008
Attractiveness			*r* = 0.429 *p* = 0.006	*r* = 0.308 *p* = 0.052	*r* = 0.352 *p* = 0.024	*r* = 0.371 *p* = 0.017
Tidiness				*r* = 0.230 *p* = 0.154	*r* = 0.081 *p* = 0.620	*r* = 0.111 *p* = 0.492
Usefulness					*r* = 0.610 *p* = 0.000	r = 0.657 *p* = 0.000
Valuableness						*r* = 0.816 *p* = 0.000

Grey Infrastructure

	Safety	Attractiveness	Tidiness	Usefulness	Valuableness	Necessity
Safety		*r* = 0.004 *p* = 0.980	*r* = 0.305 *p* = 0.055	*r* = 0.567 *p* = 0.000	*r* = 0.576 *p* = 0.000	*r* = 0.462 *p* = 0.002
Attractiveness			*r* = 0.194 *p* = 0.230	*r* = 0.178 *p* = 0.266	*r* = 0.173 *p* = 0.280	*r* = 0.188 *p* = 0.239
Tidiness				*r* = 0.291 *p* = 0.069	*r* = 0.071 *p* = 0.664	*r* = 0.205 *p* = 0.205
Usefulness					*r* = 0.603 *p* = 0.000	*r* = 0.456 *p* = 0.003
Valuableness						*r* = 0.495 *p* = 0.001

Appendix 6
Explicit preferences for Blue-green and Grey Infrastructure calculated using different selections of evaluative attributes.

Evaluative attributes	*TD score*	*Range*
Safety, attractiveness, tidiness*, usefulness, valuableness and necessity	0.66 (0.52)	−0.36 to 1.55
Safety, attractiveness, tidiness*	0.74 (0.61)	−0.60 to 2.00
Safety, attractiveness, tidiness*, necessity	0.66 (0.50)	−0.65 to 1.40
Safety, tidiness*, necessity	0.33 (0.58)	−1.47 to 1.59

Standard deviation is given in parentheses, $n = 41$.
*Tidiness or maintained in the US tests, which is common vocabulary to describe the appearance of Blue-green Infrastructure.

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Making climate public: energy monitoring and smart grids as political participation

Hannah Knox

Abstract: This article presents the findings of ethnographic research in the UK with a network of engineers, activists, and citizens involved in developing smart energy monitoring systems and community smart grids. The paper explores how everyday uses of data, material evidence, and sensory information on material and thermodynamic processes that appear in such projects, are opening up new spaces for public participation in climate change politics. Here, familiar discursive and deliberative forms of democratic participation are supplemented by what I term *material diagnostics*—a practice of public participation that revolves around a collective effort to unpack and rethink infrastructures as sites of climate action. Building on these findings, the paper suggests that everyday digitally informed experiments with urban infrastructures have the potential to extend the kinds of political subjectivities and participatory politics that are possible, as governments seek to transition to a net-zero future.

Keywords: Public engagement, climate change, digital, data, anthropology, ethnography, participation, publics, community, energy.

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Introduction

I have been following Tom[1] on Twitter ever since I went to speak to him about his experiences of home energy retrofit, smart metering, and his ongoing attempts to reduce his carbon footprint through changes to his home and lifestyle. Today he has tweeted a picture of a new grey box propped up against his house, with the words '*and so it begins*'. Although the heat pump is still to be wired and plumbed in, Tom is nonetheless proud to show off the new device, which will run alongside a solar battery further supporting his moves to energy efficiency through energy saving and microgeneration of electricity. The air source heat pump is just the latest in a series of energy-saving and energy-transforming technologies that have come to be a part of Tom's life over the past few years. Starting with a housing retrofit project which saw the complete overhaul of his home's insulation, Tom has, ever since, been a stalwart of energy technology innovation in the Northern English city in which he lives. An avid monitorer of his everyday energy use and prolific Twitter user, Tom has become a public advocate for climate-change oriented technology and voice-piece for the reflexive considerations that becoming rewired into a post-carbon electricity system might mean for people and the planet.

I first met Tom seven years earlier at a workshop that I attended as part of ongoing ethnographic research on urban climate change mitigation, where we were learning for the first time how to build our own DIY digital home energy monitors. The workshop was organised by an energy cooperative that was exploring new ways of helping homeowners understand their energy use, showing them how to share the data with the community, and exploring the impact of installing energy-saving technologies such as insulation and solar panels into their homes. Working at the intersection of climate change activism, urban climate change policymaking and digital technology development, the work of this cooperative was part of a broader community energy movement, which in recent years had begun to explore the role that smart meters, smart grids, and new forms of digital data might play in the transition to a zero-carbon future.

This paper takes as its focus the activities of this energy cooperative, its network of participants and its experiments with smart meters and smart grids, to explore how digital, data-inflected attempts at infrastructural transformation are creating a distinctive form of public participation in the problem of climate change. One of the challenges that climate change activists and policymakers often highlight as an obstacle that needs to be overcome in the transition to zero-carbon, is the issue of how to engage a broad public in both the challenge of climate change and in shaping the solutions to this often seemingly intractable and divisive problem. Attempts to

[1] All names and organisations have been given pseudonyms.

constitute climate publics in the UK context have been varied. They extend from long-running practices of climate activism, which seek to use direct action, protest, and disruption to make visible to unaware publics the otherwise often invisible problem of climate breakdown; the publication of high-level independent policy reports alongside the publicisation of scientific findings in the mainstream press which seek to gain public interest through (arguably limited) media reporting; and more recently the creation of climate citizen assemblies—deliberative fora through which a wide range of views on climate change policy options can be debated, discussed, and discursively agreed upon. In each of these cases, the public is constituted as a discourse-community whereby either passively (as imagined community) or actively (as forum participants) people are framed as interlocutors in a debate about what should be done about climate change.

In this paper I seek to expand this sense of what public participation in climate change might look like. Building on research into the everyday work that goes into the making of low-carbon infrastructures, I point to the distinctive qualities of a 'climate public' that I found to be emerging in and around the community smart grid projects I researched. Whilst clearly a rather niche form of participation in climate change, I suggest that the nascent climate public which I explore in this paper, provides us with an opportunity to expand our sense of the spaces where public action on climate change is taking place, and to reimagine possible forms that it might take in the future.

Infrastructural publics and climate change

In recent years, the notion of the public as constituted primarily in a discursive and deliberative register has been challenged by various social science scholars who have drawn attention to the way people are situated as publics not only through language and discourse, but also through their relations to objects, materials, and technology (Anand 2011, Braun & Whatmore 2011, Latour & Weibel 2005). One key area of research in which this has been illustrated most clearly, is in work that has focused on people's engagement and entanglement in infrastructural systems (Anand *et al.* 2018, Boyer 2019, Harvey *et al.* 2017, Knox 2017). Recent work on environmental and urban infrastructures has shown that publics are not only constituted in relation to protest, media discourse, political deliberation, and democratic debate, but are also made and remade as collectives in and through mundane, everyday material and technical engagements with infrastructures of different kinds. When a new road is built, a windfarm proposed, or a housing estate planned, such projects draw out and materialise latent relationships between communities, officials, engineers, landscapes, chemicals, bodies, and livelihoods. Infrastructures are projects where, as de Boeck evocatively puts it, 'publics thicken' (De Boeck 2012).

Recent work on climate urbanism has starkly illustrated how climate change is an infrastructural problem (Castán Broto *et al.* 2020). Reducing the carbon emissions of cities and creating resilience against future climatic effects in urban settings has been shown to be a project that will demand a fundamental transformation in the infrastructures through which cities and nations function. The buildings in which people live, the vehicles with which they move, the energy that powers homes and businesses, the food that people eat, and the goods that they buy are all being reconsidered in light of climate change. Each of these infrastructural transformations is a moment not only of technical change, but also a process in which people are being invited to engage as particular kinds of publics: whether the oppositional publics of public consultation, the passive consumers of smart city infrastructures, or the infrastructural publics of community energy projects.

This paper draws attention to a particular aspect of climate urbanism as infrastructure transformation, which appeared as central in my own research, namely the key role that digital technologies—in the form of smart meters and smart grids—were playing as components of these shifting urban infrastructures. Intriguingly, digital technology use in climate urbanism has been a relatively unexplored dimension of public engagement in infrastructural climate politics. A recent collection on the emerging concept of climate urbanism, for example, makes scant mention of digital practices, data analysis, or sensory technologies in an otherwise far-reaching and field-defining assessment of climate change in cities (Castán Broto *et al.* 2020). This is perhaps due to the deep-seated association of climate change with ecological or environmental relations, a framing which can sometimes reproduce a cultural separation between the domain of the natural environment on the one hand and activities of a digital techno-culture on the other (Knox forthcoming 2022, Latour 1993). And yet climate change is deeply inflected by digital technologies. The models through which climate change has been detected and made into an object of global policymaking are some of the largest and most sophisticated computational systems that exist in the world today: climate change is arguably the original big data problem (Edwards 2010). Future decisions about climate solutions are framed by Integrated Assessment Models (IAMS)—experimental computational models that perform cost–benefit and risk analyses by juxtaposing economic, energy, and climate data in future-world scenarios (Edwards 1999, Hastrup & Skrydstrup 2012). Digital systems are also contributors to climate change, with emerging technologies like bitcoin and AI (artifical intelligence) demanding huge and increasing amounts of energy to function (Mora *et al.* 2018). At the same time, advanced digital systems of mapping, monitoring, and data processing are themselves being used to generate data visualisations, sonifications, and digital mapping of entities like rooftop solar potential, energy grids, environmental degradation, and migration patterns, which promise to operate as key devices for making the shape, feel, and affect of climate perceptible to experts and publics (Gabrys 2016, Houser 2014, Lippert 2015).

If infrastructures are sites where 'publics thicken', digital infrastructures have been shown to generate their own particular dynamics of public participation. A key insight of recent work on digital systems has been the way that such systems appear to be reconfiguring existing understandings of power and political relationships. On the one hand, the rise of global corporations, like Google, Facebook, ByteDance, and Amazon, appears to have shifted the primary site of governance and power from states to corporations who now control populations and their actions through their use of data mining, analytics, machine learning, and AI (Zuboff 2019). The way search engines and social media sites have shifted from tools designed to effect social connection to engines for the production of commercialisable data, has raised new questions about the 'public' nature of participation in platforms which use publicly generated data for private gain (Ruppert *et al.* 2017). On the other hand, digital technologies have in other contexts afforded a countercultural, libertarian or activist response to their potential for social and political organisation, generating the birth of things like the Free and Open Source movement (Coleman 2009, Kelty 2008), or the quantified-self movement (Nafus 2016) in which people have reinstated ideas about participation, democracy, free speech, and individualism through the medium of digital technologies, sensors, and software. Jeffrey Juris's work on digital activism, for example, has drawn attention to the way digital platforms have offered new ways of making global political networks, as well as raising their own challenges in terms of how to keep people engaged longer term in online activist networks (Juris 2008). Other digital infrastructures, such as the emergence of free and open source software (F/OSS), have been shown to be generative of what Chris Kelty has termed 'recursive publics': that is, forms of public participation in software generation that create open and public infrastructure whilst simultaneously positioning programmers as themselves constitutive of digital public sphere (Kelty 2008). From the top-down and from the bottom-up, digital platforms and data systems have been shown to be profoundly important sites for the negotiated rearticulation of what collective public life means, and the reconsideration of the appropriate or available forms of participation in this public life. If infrastructures have long been sites where publics are made and remade, digital infrastructures have introduced particular issues which need to be considered if we are to understand the kinds of public participation that contemporary grassroots climate change infrastructure projects are beginning to generate.

In what follows I draw on twelve months of ethnographic research with a community-based energy cooperative and their network of partners to explore how engagement with smart grids, smart meters, and data flows are framing the contours of public participation in climate politics. The research involved one day a week of participant observation with the energy cooperative with a particular focus on their involvement in a European Smart Grid Demonstrator Project. In addition, I participated in in several project meetings (virtual and face to face), conducted weekly informal interviews with staff of the energy cooperative, carried out seven recorded interviews with other members of the energy co-op, four recorded interviews with partner organisations participating in the EU project, and participated in broader activities related to municipal and community energy opportunities, including involvement in a collaborative research project into options for a municipal cooperative energy company involving grid operators, union representatives, and local policymakers. The research also involved archival research on the history of electricity infrastructure in the city where research was primarily conducted, consultation of reports and grey literature on UK and European community energy initiatives, and the organisation of a 'hackathon' involving policymakers, technical experts, and energy system employees, which addressed the question 'how can energy be made more equitable'.

Drawing on this research I explore how engagements with climate change, inflected through an attention to digital data emerging from the use of meters in community smart grid projects, are creating what I term 'infrastructural publics'. Confronted with information on material flows and energy relations, I suggest that people involved in such projects find themselves newly aware of their entanglement in infrastructural systems, with implications for ideas about political responsibility, agency, and the form that political action in the face of climate change might take.

Rewiring community with smart grids and meters

It is a rainy Thursday in September and a group of around thirty members of a European Community Smart Grid Demonstrator project are gathered outside the meeting room where the project feedback meeting is about to start. Some are slumped on sagging sofas, heads burrowed in laptops, others talking to colleagues with coffee mugs in hand, some seeking out a working projector or looking for a reliable Wi-Fi signal. Emailing, texting, preparing, testing, the group are getting ready to present to the project funders, their latest work to build, implement, and test a prototype community smart grid system.

NewGrid is a European project with partners in Belgium, Greece, Italy, Spain, and the UK. The partners at the meeting, including the project assessors from Brussels, have travelled from across Europe to the Old Mill Building at Northern Co-Housing, a housing cooperative on the edge of a town in the North of England, and one of the test sites for the NewGrid project. The meeting is ready, chairs lined up, and so we take our seats, ready to be welcomed by the Co-Housing group director who opens the meeting by explaining why an eco-housing cooperative might be interested in being involved in a technology project like this.

In the presentations that follow, the NewGrid project is explained. The aim of NewGrid is to demonstrate the feasibility of creating local, smart electricity grids that could potentially be used by cooperatives, local distribution service operators, and communities to generate, manage, and supply their own electricity within a particular locale, neighbourhood, or social network. To do this the project has brought together partners from across Europe with expertise in engineering, software development, and community engagement to build smart meters that will monitor electricity use; collate information into a central repository; and give different participants—citizens, grid operators, and communities—access to data that will enable them to better understand and manage their energy use. The aim of the project is to ultimately redesign, through the use of digital technologies, the socio-technical infrastructures that currently structure people's relationship with electricity. This is summarised on the project website in the following policy-oriented terms:

> The main outcomes of the project are ICT tools that offer secure, stable and robust smart grids, allowing distribution service operators (DSOs) to mitigate management, replacement and maintenance costs of the electricity distribution grid, in presence of large share of distributed renewable energy resources.
>
> The project proposes innovative business models for the new players in the electricity panorama, such as prosumers, aggregators and energy service companies, with the objective to facilitate the integration of next generation distributed renewable energy sources and active participation of the European citizens in the energy market (demand response schemas).
>
> … The most innovative aspect of the project is the innovative and affordable smart low-cost advanced meter allowing more extended functionalities for consumers and prosumers in order to empower and protect European citizens.

Although this website text offers a rather abstracted and technical description of the project's aims, conversations with its members and the presentations at the workshop suggest that its technical ambitions were understood to be radical, environmentally driven, and deeply political. The five test sites for the project were all electricity cooperatives or non-profit organisations, who had long been working to explore how to effect a move away from fossil-fuelled capitalism and bring in a more ecologically and socially sustainable way of living with energy. This ranged from a project in Northern England which sought to reduce people's energy use through proper insulation and a greater sensitisation to the thermodynamics of houses; a project in Catalonia in Spain which was seeking to create incentives for citizens to invest in distributed energy generation by investing in a solar cooperative, and explorations of the possibility of keeping the economic benefits of renewable energy generation in local places through the development of peer-to-peer energy trading. What held these projects together was the ultimate aim to bring about a fundamental rethinking of the 20th-century model of how electricity has been generated, distributed, and supplied in Europe through the development of an alternative energy infrastructure.

Reworking the electric public

Northern Co-Housing, where the workshop was being held, was to be one of the test sites for the project. In the UK, testing the functioning of community electricity grid systems had proved quite difficult to achieve, constrained by technical infrastructures and regulatory systems that had been developed in the context of the creation of an analogue, fossil-fuel-powered national electricity grid in the early 20th century, and the later privatisation of the electricity industry in the 1990s (Nolden *et al.* 2020). One of the key aims of the creation of a national electricity grid in the late 1920s, had been to integrate an otherwise fragmented system of different voltages, appliances, and systems that had sprung up in local areas all over the country by standardising the distribution and supply of electricity with one national system (Hughes 1983, Luckin 1990). A key principle that this centralised grid had worked with was that electricity would be available to all citizens at nationally standardised cost, so that those who lived far from sites of electricity generation were not disadvantaged either in terms of reliability of supply or cost. We might say that in this way the national electricity grid, even before the wholesale nationalisation of the energy industry in the mid-20th century, had begun to usher in the idea of a national energy public (Bakke 2016, Hughes 1983, Latour & Weibel 2005, Özden-Schilling 2015, Özden-Schilling 2016).

The more recent emergence of location-based, community, and municipal energy schemes, brought about as a result of the emergence of distributed and localised forms of electricity generation through solar panels, heat pumps, or community energy cooperatives was posing a potential transformation of this model of electricity as a public good for a national citizenship. This had raised concerns that sub-national energy generation and supply could have a divisive effect, potentially meaning communities or groups with greater access to energy resources would gain advantage over those with no access to energy generation. For this reason, regulatory restrictions were in place in England at the time of this research, that prevented communities from being able to sell locally generated electricity directly to local electricity users. Instead individuals and communities that generated electricity still had to give back any of the energy that they did not use themselves, to the national 'pool' of electricity, which, through market mechanisms, became once again distributed as a form of national resource through the national grid (Nolden *et al.* 2020).

Luckily for the NewGrid project, Northern Co-Housing was something of an anomaly in community energy terms. Unlike community energy groups that brought together individual households which were each, already, connected to the national grid, Northern Co-Housing was what was known as a 'behind the meter' cooperative. Northern Co-housing is made up of a group of forty-one houses, over thirty micro-businesses, and several communal areas, and was developed on a single site in the early 2000s. The whole site was connected to the national grid through just a single point, with the electricity measured through a single meter. This meant that what happened 'behind the meter' was invisible to the national grid, making it an ideal site for an experimental community smart grid project that could play around with the possibilities of reconfiguring demand and supply outside national regulatory infrastructures. For the community, what being behind the meter had meant in practical terms was that energy that was already being generated from solar panels and a hydroelectric generator and used on the site by households and small business units, and needed to be managed not by the usual billing structures of a commercial energy supply company but by one of the community members.

One effect of this arrangement was to constitute Northern Co-Housing not as a group of individual homeowners managing their own electricity consumption, but as a proto-collective that was experienced by Co-Housing members as existing in tension with the national energy system. Up until this point, the management of the site's electricity had fallen on the shoulders of Simon. It had been Simon's job to annually go around to each of the houses and business units on the site and read their electricity meter, writing the numbers down in a notebook and transferring them onto his computer. Simon had then had to work out the relationship between the electricity generated on site by the small hydroelectric generator and solar panels, the amount of electricity that everyone used, the amount of electricity used by shared spaces—including the electric car club and a shared common room—and the amount being charged by the electricity company, in order to come up with an accurate bill for each household or business. Up until this point Simon had taken on the role of a kind of local grid controller—a 'job' for which he was not remunerated. The NewGrid project proposed to transform the community's ability to manage its energy use by digitising the monitoring and management of the site's electricity, replacing Simon with a centralised system of energy monitoring and display that could potentially be visible to anyone on the site. By adding smart meter extension units to sites of generation (the water mill and the club house where the solar panels were located) and also to the sites of consumption (namely the houses, business units, and an electric car charging point) and deploying a user-interface where this data could be analysed, the project sought to use smart meters and smart grids to give Northern Co-Housing residents a new-found control of their electricity use. However, as mentioned above, the effect of the putting in place local smart metering was not to individualise the management of electricity consumption but rather to increase the collective power of the site as an energy community. This was in direct contrast to the way that smart metering has often been understood as a technology neoliberal control.

Socialising with smart meters

The NewGrid's project to develop smart meters for the purposes of supporting community energy was being deployed in the UK in the context of a broader approach to smart metering that had been in place since the early 2000s. In 2012, the UK government had announced with some fanfare that by 2020 every household in the UK would have a smart meter in their home. The aim of smart metering in this national project was multiple: a pragmatic attempt to prevent the need for in-person meter readings by supply companies; a technical tool to link to the broader digitisation of the electricity grid to help grid operators identify faults on the system in real time and to resolve them remotely and quickly; and most crucially for our purposes, a way to give customers data on their energy use so that they could focus on how to use energy more efficiently.

Much of the marketing and enthusiasm for the national smart meter programme was promoted on this latter basis. Smart meters were primarily touted as a tool that would help people visualise their energy use. On the basis of this visualisation, it was argued that they would be able to make better choices about their individual energy use, saving money for themselves as consumers as well as indirectly contributing to nationally mandated targets for the reduction of energy for environmental reasons. Meters in the context of the national smart meter rollout functioned as a tool that addressed individual consumers, or households, asking them to enact themselves as part of a national public through a reconsideration of their own individual consumption habits within a system of inputs and outputs not unlike that of the smart city. Metering in general, and smart metering in particular, has thus been widely described as a tool of neoliberal governmentality, in that it seeks to ask individuals and households to self-discipline their energy use in response to data that is read as informational and transparent in its meaning (Coleman 2014, Schnitzler 2016).

Responses to this have been varied. Sociologists working in the field of energy practices have been deeply critical of a naive technological determinism which has often imbued projects that assume that data on energy use is transparent in its meaning, and predictable in terms of its social effects (Shove & Walker 2014, Shove *et al.* 2014). Such studies have shown that energy practices are not behaviours that can or should be nudged with objective information to prompt rational attempts to save money or reduce carbon emissions but are deeply entangled with ideas about comfort, kinship, home, and responsibility (Hand *et al.* 2005, Shove *et al.* 2014).

An alternative, and less directly critical, approach to energy monitoring comes from those who have been interested in what the emergence of environmental data might tell us about broader shifting structures of social relations. Going beyond the idea that citizens are either units of behaviour that can be technically manipulated, or that they are social beings embedded in webs of meaning that directly contradict the ambitions of policymakers and technology developers, some more politically minded scholars have sought to address the broader philosophical and structural question of what kinds of persons and publics might be emerging as people begin to use sensory devices as a means of what Noortje Marres has termed a practice of 'material participation' (Marres 2015).

This work has suggested that what emerges when people begin to engage with and use environmental data in their everyday lives is less a straightforward nudge towards pro-environmental behaviours, than a way of being in which people's sense of themselves as persons or citizens is iteratively and constantly shaped through their sense of themselves in relation to material flows (Naus *et al.* 2015, Strengers 2012). For Marres, this takes the form of a new kind of publicness which is entangled with people's newfound sense of their domestic lives as a facet of a broader environmental ecumene that is sustained and experienced through blogs, photo sharing, and public performance (Marres 2011, 2015) . For Jennifer Gabrys, the environmental subjectivity that comes from an engagement with environmental data is not just a new way of performing the self but is also entangled with new modes of governmentality that seek to survey and control emerging publics through disciplinary techniques of monitoring and automation (Gabrys 2014). For Gabrys, this creates an experience of urban citizenship as constituted through a governmental practice that she terms 'environmentality'. Here the individual is no longer constituted as a citizen through their incorporation into a broader public as a site of discourse and practice, but is now constituted as a node or data point within a terrain of data-mapped relations. This is demonstrated in Gabrys' work through an attention to air quality monitoring, in which the driver of a car, a factory, or a household that burns coal, become visible into the urban data dashboard as equivalent units that both contribute to and shape the 'problem space' of urban air quality (Lury 2021, Mattern 2015). Akin to analyses of big data analytics as a mode of platform governance or surveillance capitalism, environmental data in this framing highlight the way that digital sensing has the capacity to enact a top-down, data-driven refiguration of social life.

In the case of the smart metering and smart grid projects that I followed in my research, the implications of new forms of environmental data for people's sense of themselves and their place in the world appeared less as a form of imposed 'environmentality' than, what I have come to term elsewhere, a more bottom-up practice of material or infrastructural diagnostics (Knox 2020). To participate, through attention to data of different kinds, in a material diagnostics was in this case not the transformation of the urban citizen into the subject/object of environmentality—nodes in a system of information exchange. In contrast, a digitally inflected material diagnostics seemed to actually open up a renewed space of participation and deliberation, inviting people to engage in fresh ways with questions about the relationship between public and private life, which now revolved around the relational properties of materials as they became revealed anew in the practice of everyday, bottom-up energy monitoring. To explore this further, let us return to some of the people who I met in the research, who were involved at a day-to-day level in monitoring and measuring their energy.

Material diagnostics

Some months after the initial project meeting, I returned to Northern Co-Housing for a participatory workshop that sought to explore with the housing group how they might be able to make the use of the data that were coming from the smart meters. Matthew, from the NewGrid project, began the workshop by showing a slide displaying an anonymised feed of electricity data from one of the smart meters that had been installed on the site in one of the Co-Housing resident's houses. He quickly talked through the graph of energy data, before opening up the floor for a broader discussion with members of the Co-Housing community about how they would like to monitor their energy and use the data.

Although not described in much detail, the graph displaying energy data was the trigger for many questions from the group. One of the members started the discussion by asking about the baseload represented on the graph, and whether there was an app that could help them disaggregate the data so as to differentiate between the baseload of electricity that stretched out at the bottom of the graph, and the fluctuations of electricity skipping along above this. Matthew's response was that the best thing to do would be to just turn appliances on and off and make a note of what happens on the feed in real time.

Discussion then moved on to recall previous attempts to analyse the data onsite prior to the installation of the smart meters. Here stories of energy monitoring discrepancies began to be told: like the time when the aggregated data on the energy being used by the business unit tenants did not add up to the whole building's calculated energy use. This prompted an interrogation to try to work out which of the businesses this extra energy use was coming from, why it was not registering in the data, whether the meters were installed properly, or whether there were collectively owned objects which used energy but that were not being taken into account. In spite of these problems, the transformative potential of data was also expressed, with several participants coming up with ideas about projects and activities that new streams of energy data could enable. One participant told a story, for example, of another co-housing site where they had set up an alert with the sound of a dog barking broadcast over a Tannoy to alert everyone that the grid was at low capacity and they could put their appliances on. Another asked whether a traffic light system could be installed in their shared laundry room to indicate whether their renewable sources were generating electricity and if it was therefore a good time to put the washing machine on.

What emerged from this discussion was the way that engagement with even rather mundane digital data streams on energy use prompted an attention to matter and its relations through what I am calling here material diagnostics (Knox 2020, 2021). Material diagnostics was importantly not just an engagement with data itself, but a practice that took data as a prompt to interrogate a much wider set of material and social relationships in which people came to realise that they were embedded.

This sensibility came up in conversations with many other people I spoke to during the course of my research. As well as following the NewGrid project, I also interviewed and participated in workshops and events with a wider group of people who were members of one of the energy cooperatives that was part of NewGrid project. They too expressed a similar relationship to energy data as that which was articulated by the Northern Co-Housing workshop participants, with energy data opening up a diagnostic relationship with ready-to-hand materials, interpersonal social relations, and broader infrastructures of energy supply, distribution, and generation.

When I went to interview Tom, with whom this paper opened, he spent a lot of time explaining to me the variety of relationships to which he had become sensitised as he read his energy data. Tom's sensibility to his home and its functioning that emerged through his close engagement with energy data had initially been prompted by attempts to make his house more environmentally friendly. Over time he had worked hard to combine data from meters and sensors with information on prevailing weather conditions described through data from the Met Office, the carbon dioxide emissions associated with his travel, and how he and his family heated and lit his home. Monitoring these material properties and practices amplified Tom's awareness of many aspects of the material and ecological infrastructures that held his life in place, from his home, to where he worked, to what he ate and where he travelled. It prompted him to reflect on his ongoing use of a petrol car and partly influenced his decision to buy an electric bike and eventually an electric car.

As Tom had developed and deepened a sensibility to energy, pollution, and thermodynamics through these ongoing activities, these had caused him to go beyond a consideration of his direct material circumstances of his house to attend to other kinds of relations. These interrogations were not always intentional, with data and new energy-saving technologies often causing Tom to think about aspects of his life in ways that were quite unanticipated. One example of this was the diagnostic effects that unfolded when, after years of energy monitoring, and after installing solar panels on his house, Tom and his family decided to buy an electric car. Because it needed to be charged up through the home, and because they were trying to be environmentally conscious, the electric car needed to be parked close to the house either at times of lowest grid intensity, or when Tom's solar panels were producing electricity, so as to make the charging as ecologically effective as possible. To reach the charging point, however, the car had to be parked in the back alley that ran along the rear of the house. Tom told me that this was awkward, as it would mean asking neighbours to move their cars so that he could put his car onto charge:

> *People can park at both ends and block us out—they can block us in as well. Normally, you've just got to knock on their door and say 'you're blocking me in', but if it's just 'you're blocking the street I want to plug my car in' I don't feel like, really I should go and bother them for that.*

Asking people to move their cars to access a street in order to charge an electric vehicle at times dictated by data on environment properties and relations felt different to asking people to move their cars so as to get one's own vehicle out to drive it. The reason for why this was the case was left hanging, with Tom simply saying '*you know what I mean?*' And I felt like I did. In the context of the rest of the conversation it did seem like it might be presumptuous to knock on a neighbour's door and interrupt them for what might have been seen as an indulgent, selfish, or inflexible demand to plug a vehicle in at an otherwise seemingly idiosyncratic time of day. Material diagnostics in this case, was not only about tracing out the implications or possibilities brought to the fore by data, but also attending to the implications of the decisions that were informed by the informational flows that energy data produced: implications which pitted being an infrastructural public against being, in this case, a good neighbour.

This issue of the unfolding, and ongoing process of sensing, analysing, interpreting, and then trying to act appropriately was explained to me once again when I went to speak to another interviewee. Eric was a climate scientist by profession. He had become particularly involved in energy monitoring as part of an eco-renovation project to transform an old vicarage that he and his wife had bought. He had told me how he had been interested from the outset in monitoring his data. He was very comfortable with using spreadsheets to calculate material properties and told me he used spreadsheets extensively in the project. Nonetheless, as Eric became more sensitised to questions of energy and materials, he found himself moving away from spreadsheets of energy data, and incorporating a more expansive experimental and materially explorative approach to his renovation project.

One of the surprising effects of attending, first through data, and then through materials, to the complex and unfolding social–material world of energy transformation, was that it opened up the possibility that existing ways of doing things could be done otherwise. As Eric and I discussed the process of retrofitting the old vicarage, he started to tell me how a data-driven attention to the energetic properties of his new home prompted a material inventiveness and creativity that he did not initially anticipate.

One story he told me was the conundrum they were faced with when they wanted to insulate an arched window. The builder had never encountered anyone who wanted to insulate an arch before, and so Eric set about working out a way to go about the task. He first consulted an architect friend who was helping with the retrofit project, who sensitised him to the basic language he needed to understand what a window arch was in architectural terms (the wall as 'reveal', the 'kiss' where the wall and ceiling meet). Analysing the arch 'reveal', they realised that the archway was not straight but was actually a 'section through a cone' and so, finding an online cone calculator Eric found himself able to work out a way of calculating the area that needed to be insulated and the shape the insulation would need to be:

> *So I put the measurements in for the size of the windows. And then built myself a giant protractor—on the floor. So I used a bit of string on a chair leg and a bit of wallpaper roll. And then drew these conical sets. And then put them over this flexible insulating blanket. And then we cut out the right shape. And then Dylan* [the builder] *thought of a way of using some old polythene pipe around the inside as a frame. And we screwed and stapled onto the pipe. So that's how we ended up with the curved insulation.*

Having taken two days off work to be with the builder and to make this intervention, Eric reflected '*It was fun, and I'd like to think he was my friend now and not just someone I've given tens of thousands of pounds to over nine months work!*'

In this case the experimentation led to a renewed relationship with his builder, built out of an explorative and environmentally attuned relationship with materials. It also meant a new-found understanding of buildings—from the terms used to describe them, to the history of insulation techniques, to the way that builders often seemed to work not through concrete calculations but through more of a 'rule of thumb' approach. Other stories that Eric and Tom told me opened up detailed analyses of the functioning of the solar panel industry, government regulations on feed-in tariffs, an analysis of the relationship that they had historically had with their energy company, how such companies provided data (or not), and the kinds of possible relationships that they might be able to forge in the future with alternative energy generators, suppliers, and technologies.

It could be argued that the material diagnostics that characterised people's engagement with digital and data-mediated environmental processes are simply an extension to the kind of diagnostics that has always been a part of working with ready-to-hand materials and their properties (Ingold 2002). Nonetheless, I suggest that the use of data—on electricity, thermal properties, or cost—not only invited people to engage with materials and their properties, but invited those installing energy-saving technologies or smart meters, or retrofitting their houses, to locate themselves and their material relations within a wider social, infrastructural, and environmental set of relationships that was constantly brought back into view by environmental data. In all the interviews I conducted, people moved in and out, from data analysis on specific issues of energy usage to a broader form of questioning about the way that energy positioned them within existing social and energetic infrastructures, and then back into energy data. It is this experience of being made aware of being part of a complex, entangled, infrastructural systems of relations—which often conflicted with other forms of conducting social life, and over which people frequently realised they had relatively little control— that I refer to as the experience of being part of an 'infrastructural public'.

This brings me to a final point about these practices of material diagnostics that become revealed through an attention to digital environmentalism: that is, the way that these practices become themselves made public through the use of digital platforms and networks. In the case of all of the people and projects I have discussed, the actions taken to reduce energy, be more environmentally friendly, change housing methods, insulate buildings, or attend to thermodynamics were oriented not only to the direct benefits they would generate for individuals, or even the intimate interpersonal relations they established or transformed, but also to a wider sense of enacting a way of being part of a nascent climate public that might collectively start to act upon these infrastructural systems.

Recall the opening example of Tom's Twitter feed. Tom's material diagnostics had moved over time from being a personal project of energy monitoring to a public demonstration of what becomes possible when environmental monitoring becomes part of one's way of being in the world. Even before installing smart metering and monitoring in his home, Tom had started to help other people who belonged to the same energy cooperative learn how to read their energy meters, collate the information in spreadsheets, and begin to discern patterns over time. When Eric told me about another part of the retrofit process, a heat-recovery unit for their hot water pipe that was feeding his shower and '*our only bit of eco-bling*'—he told me he was still a bit sceptical about the ecological benefits of this expensive piece of equipment but that he would do it again in his own home because '*it's an interesting one to talk about because it makes people think about hot water*'. Both Eric and Tom had taken albums-worth of photographs of their retrofit process to share with others who would be interested in doing the same thing. Another couple who I went to speak to who were also thinking of installing a smart meter in their home after having undergone a major renovation to make it more energy efficient, told me of their desire to build a political movement around what they had learnt through their own attempts at saving energy. They were overtly sceptical of the government's smart meter programme, which they saw as a corporate scam, but at the same time, they showed me a large A4 notebook in which they had carefully monitored their own energy use over the past several years, juxtaposing energy data with other forms of environmental observation, and told me of how they wished to inculcate a similar sensibility in others by building a network of activists through email and conversations like the one we were having.

Returning to the NewGrid and to Northern Co-Housing's involvement in this project, both of these were also framed in terms of their orientation towards a refigured public that might unfold through the detail of engagement with energy infrastructure and its digital possibilities. NewGrid framed itself as a demonstrator of what could be possible when urban and community grids were redesigned using digital systems. What emerged was the prospect that digitised energy systems might reconstitute the scale and scope of what an energy collective could look like. This might take the form of peer-to-peer energy trading that would create new collectives out of networks of citizens repositioned as energy generators, or alternatively the invention of place-based community power stations that would become energy suppliers to local areas. The idea of the community power station was a topic that several Northern Co-Housing residents were fascinated by, hoping that eventually the connective and informational possibilities of a functioning smart grid might enable them to forge social, economic, and energetic links beyond their community to a local village, allowing them to share their locally produced electricity with others that they cared about and with whom they wished to forge stronger bonds. As my fieldwork with the NewGrid project drew to a close, its participants were continuing to interrogate digitally enabled alternatives to energy generation. These were now opening up from discussions of local communities as sites of energy generation, to further talk of municipal energy companies, regional power networks, and cooperatively owned place-based energy service companies (ESCOs). These discussions and experiments, grounded in a practice of digitally inflected material diagnostics, entailed nothing less than the working out and bringing into being, through the bottom-up design of technical systems, of a vision of a new kind of social contract between people, energy, and environment.

Conclusion

In his historical study of the emergence of electric light in 19th-century Europe, Wolfgang Schivelbusch describes the effects of the incursion of gas pipes and electrical cabling into people's homes (Schivelbusch 1988). As private companies laid infrastructure from the street into people's living rooms and bedrooms, this transgressed a carefully policed bourgeois boundary between the realm of public life, and the private domestic interior.

> The unease about gas and electric light in the nineteenth century can now take its place in a larger setting. Like daylight, this sort of light had an outside source. Ostensibly burning in the middle of the room in the lamp, its real origin was in the gas-works or in the central electric supply station, that is, in big industry, from which the bourgeois psyche tried to separate itself as it did from the public sphere. Just as the public sphere gained access to the home with daylight, so big industry forced its way in with the light of the gas flame and the electric bulb. (Schivelbusch 1988)

In a similar way, smart meters and smart grids now bring data feeds, Wi-Fi connections, digital visualisation, and smart appliances into the domestic space of the home. However, if 19th-century families struggled with the incursion of the public realm into private domestic space, I have suggested that the sensitisation effected by environmental data, at least among my environmentally attuned interlocutors, seemed to point to an embrace of the new-found experience of 'being infrastructural'. Monitoring and connecting had the effect of constituting these people as part of an infrastructural public, to such an extent that people would actively turn their homes into an object of public deliberation. This making infrastructural of homes and houses through insulation, grids and smart meters, and batteries, not only generated the grounds for the emergence of an infrastructural climate public, but also reinvigorated conversations about the place that collectivities might play in this public sphere of material participation and the appropriate scale at which they might most effectively work.

The activities that I have focused on in this paper were the practices of a rather niche group of individuals—technically competent, financially secure, environmentally concerned, and politically left-leaning. However, the finding that engaging in infrastructure through digital technologies has the potential to stimulate participation in climate change discourse raises the question of what kinds of climate publics might become possible if infrastructure planning and ownership were returned to individuals and communities.

We have seen in the cases presented here, how data on material properties, particularly when collated and revisualised through smart metering and smart grid systems, reframed the conditions of possibility through which action in the world could be pursued. What seemed odd, or impossible, or strange without a sensibility to thermodynamics and energy infrastructure afforded by meters and grids—insulating an arch, recovering heat from a shower, or thinking about energy in extensive terms that went beyond one's own energy bills and the four walls of one's home—now seemed possible, and indeed logical. Enthused by this opening up of an alternative way of thinking about and engaging with urban environment recast in terms of energy, digital environmentalism came to re-pose the question of public participation reframed in terms of energy relations.

In this paper I have sought to unravel the idiosyncrasies of actually existing engagements with smart grids and smart meters, with a view to showing how engagement with contemporary infrastructure has the potential to play a crucial, if under-appreciated, role in urban climate politics and the making of infrastructural publics. In direct opposition to the hyperbole and techno-modernism of smart city proposals that see urban life in terms of computational operating systems, with people and resources conceived as inputs and outputs that need to be manipulated and managed, this paper has shed light on how people who have access to the design and ownership of infrastructure, are using digital systems in their everyday lives as they seek to live with and through the challenges of climate change and situate themselves as climate publics. I have suggested that this form of digital environmentalism is a practice that augments material sensibilities, with the effect of creating ways of reinhabiting the city through the publicisation of hidden or privatised infrastructures and practices of diagnosis, and a querying that can support intervention into, and transformation of, such infrastructures.

What we find, in the everyday use of smart meters and grids, then, are the seeds of a climate public that is both broader than the niche of environmental activism but more specific than the notion of a general public that must be engaged to 'do something' about climate change. Whilst informed by environmental concerns, which were often the trigger for involvement in these practices in the first place, technology use among my interlocutors invited a form of engagement with material infrastructures, which simultaneously revealed and diagnosed the arcane and sometimes bizarre energy systems that existed behind walls, under floorboards, and beyond the plugs. Data traces opened up questions about relationships that did not always conform to existing or established boundaries: between the family and the individual, the private and the public, community and the state. It led to a tracing and a questioning of fundamental questions of the possibilities that might exist for participating in public life, recast as life lived in and through infrastructure.

Whilst this paper has focused on people's use of smart meters and community grids to reconfigure and understanding of energy systems, there are signs that similar dynamics might be observed with other kinds of digital environmental practices. Air-quality monitoring has similarly led to activities that have sought to remap urban spaces in terms of pollution hotspots, creating public campaigns and creating an impetus for redesigning streets for people rather than cars. Urban litter picking collectives find themselves mapping litter collection, sharing successes on Facebook, and tagging fly-tipping on council run websites, creating new relations of care with urban landscape. Similarly the monitoring of chemical residues in towns and regions afflicted with industrial pollution, have led to the visualisation of the effects of such residues on bodies, food, and wildlife, engendering an activism which deploys bottom-up citizen-produced data against corporate power. And indeed even these distinctions are possibly too rigid. Beyond the walls of government departments or the carefully policed boundaries of academic disciplines, these various forms of digital environmentalism in the city blur the boundaries between energy, biodiversity, waste, transportation, food, or heat as sites of environmental transformation. Too often digital sustainability takes a top-down approach to how digital systems could be used as technologies of surveillance, management, and control in ways that fail to recognise the creative, disruptive, and transformative ways they are already being incorporated into urban life. In drawing attention to everyday digital environmentalism, this paper has sought to show, through a more grounded, ethnographic understanding of urban climate change, new possibilities that are emerging for rethinking the future of cities and citizenship, as sites of entangled social and political and ecological relations.

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Reparative innovation for urban climate adaptation

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Abstract: Scholars of climate urbanism have raised the conundrum that action to address the ongoing challenges of climate change in cities have distributional impacts, deepening existing inequalities. This challenge is related in part to the ideas of urban innovation that dominate climate responses. Disruptive innovations are directed towards the rupture of existing systems of knowledge, seeking to create new ways of looking at the problem. The emerging scholarship on climate urbanism suggests that measures to adapt to climate change in urban environments heeding a disruptive narrative have uneven impacts and too often disadvantage the most vulnerable communities. In this article, we ask what it means to look for reparative innovation for climate change adaptation instead. Reparative thought has influenced different debates on climate change adaptation and other issues related to social justice, from dealing with the aftermath of conflicts to engaging in reparative experiences to deal with trauma. Critical theory has also looked into reparation as a means to engage with reparative understandings of cultural objects and heritage. We argue for a focus on reparative innovation to open up alternative innovation frameworks that acknowledge existing material urban histories and engage with the multiple forms of knowledge within the urban experience that support climate adaptation.

Keywords: Urban adaptation, urban transformations, urban infrastructure, disruptive innovation, reparative innovation.

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Introduction

Adapting to climate change impacts in urban areas constitutes an enormous challenge for which resources and capacities are limited. Climate adaptation is critical in rapidly growing urban areas, with informal areas that lack appropriate services or rapidly growing peripheries where new infrastructures will be needed (Dodman *et al.* 2012, Satterthwaite *et al.* 2007). Adaptation creates new demands and new forms of thinking about social relations with the built environment and urban infrastructure.

Action for climate adaptation can have unintended impacts that exacerbate urban vulnerability (Anguelovski *et al.* 2016, Eriksen *et al.* 2021). In urban areas of less developed countries, adaptation outcomes are intertwined with histories of dispossession and colonisation, and raise questions of justice (Henrique & Tschakert 2020, Rumbach 2017). Adaptation is a fundamentally political problem, but mainstream efforts tend to curtail political debate (North *et al.* 2017, Scoville-Simonds *et al.* 2020). For example, existing development programmes may be rebranded under the umbrella of adaptation without making a marked difference in addressing the marginalisation relations that underpin vulnerabilities (Schipper *et al.* 2020).

Climate urbanism refers to a growing wave of critiques about how cities have become central places to address climate change, both in terms of addressing climate impacts (adaptation) and reducing emissions (mitigation) (Castán Broto *et al.* 2020). Central to this body of scholarship is a concern with the impacts of climate action: creating a resilient city and resilient spaces often happens at the expense of disadvantaged populations because of the entrenched dynamics of capital accumulation and securitisation of spaces of privilege (Anguelovski *et al.* 2019a, 2019b, Long & Rice 2019). Climate adaptation could conceivably become a form of strategic urbanism to address existing inequalities (Chu *et al.* 2017). Still, in practice, the negative impacts of climate action on vulnerable populations are apparent. For example, UN-Habitat reports that cities are increasingly concerned with new forms of inequality associated with climate action. Climate protection projects may add value to the urban environment at the expense of marginalised urban groups, that may be pushed out because of changing conditions of habitation, such as increases in housing prices and rents—a process known as climate gentrification (UN-Habitat 2020).

Climate urbanism interrogates whether there are alternatives to deliver urban climate action in a just manner (Robin & Castán Broto 2020). Postcolonial analyses of urban infrastructure turn attention to do-it-yourself, makeshift, and place-based adaptations that can deliver new ways of thinking about infrastructure (Cloutier *et al.* 2018, Groulx *et al.* 2014, Udelsmann Rodrigues 2019). There are alternatives for climate change adaptation, particularly among urban citizens, but existing city-wide initiatives rarely incorporate them. One key issue is to notice and articulate place-based innovations into coherent climate policy. Innovations for adaptation often involve looking beyond highly technical systems of securitisation and control. Unlike mitigation proposals that emphasise the possibility of disrupting wider infrastructure and technological systems, adaptation calls for 'reparative innovations': that is, innovations focused on preserving adaptation capacities that address the city's past and future.

In this short article, we argue that thinking about adaptation innovations is crucial to addressing the challenges of inequality associated with climate urbanism. Our concept of reparative innovation builds upon queer theory and legal discussions of reparative justice. We further develop the concept of reparative innovation analytically, in contrast with ideas of disruption and disruptive innovation. In this way, the concept of reparative innovation brings concerns with justice to the core concepts of innovation studies. The paper concludes with a discussion of reparative innovation in the context of urban infrastructure development in postcolonial contexts. Our research agenda maps urban adaptation as a practice that must aim to be inherently reparative. A reparative understanding of innovation in urban adaptation helps reimagine adaptation actions beyond the circular debates on climate justice. Reparative innovations do not seek to disassemble the apparatus in which they are embedded, but they acknowledge and address past and present harm, making the apparatus liveable.

The promises of reparative innovations

Struggles for recognition have been part of environmental justice movements since their inception, concerned not only with the impacts of environmental change but also with the extent to which marginalised groups are excluded from their self-realisaton and self-determination (Schlosberg 2004). Climate change adds a new dimension, but forces a re-examination of collective ideas of the future and who has a hand in shaping the trajectories to those futures. The struggle for recognition has led to an emphasis on restorative justice in environmental justice movements, as a framework that emphasises reconciliation (Figueroa & Waitt 2010). Restorative justice is closely related to indigenous affective experiences of colonisation and decolonisation that offer transformative alternatives (Smith 2012). Restorative justice also invokes governmental responsibility for maintaining the restorative process and the conditions that make it possible, particularly in the context of criminal justice and, for example, environmental crimes (van Wormer & Walker 2012).

The notions of reparative justice and restorative justice are frequently used interchangeably: often, calls for restorative justice add the intention to repair. In this paper, however, we favour the notion of reparation and reparative justice because it allows a move away from formal processes to achieve justice, focusing instead on active efforts to engage with people and the world materially, through artefacts. This notion of reparative justice is a springboard to rethink innovation as a means to focus on creating new futures that climate adaptation requires. This is inspired by Linda Tuhiwai Smith (2012: 159), who refers to 'the spirit of creating that indigenous communities have exercised over thousands of years' as a means to 'dream new visions and to hold to old ones'. In a postcolonial world, reparative innovation celebrates a pluralism of knowledge that can inform climate adaptation.

Reparation is a multilayered concept that has to do with maintenance (fixing something) and making amends. That undercurrent of 'making amends' reveals that reparation relates to our relationship with others and the material world: it is about recognising having done something wrong, which needs payback for those people or things that have been wronged. Reparation thus implies an action to address the wrongs of the past:

> To hold that redressing a wrong is an obligation of justice is to hold that some remedial action is (at least prima facie) necessary, something that morally must be done (Walker 2015: 211).

Walker explains that thinking about reparative justice is different from thinking about corrective justice. Reparation is not the same as paying for a deed. A compensation for unjust harms and losses will do little to repair the loss of your home—and your life—after flooding. For people living in informal settlements where their tenure depends on holding onto space, the enormous harm made by resettlement can hardly be accounted for by compensation. Walker examines reparative justice in the context of mass violence and systemic human rights abuses, but the lessons are relevant to understanding climate adaptation. Walker explains that practical experiences in reparative justice cast it as a process in-the-making that requires a certain degree of experimentation in discovering what constitutes justice. In conclusion, Walker argues that engaging with different methods can lead to that reparative discovery.

In the context of climate change, reparative justice calls for examining the history of climate change as a problem, as a means to attribute responsibilities for reparation. However, it follows that history alone is not sufficient and that, to a certain extent, a degree of responsibility for reparations must be widespread (Thompson 2021). Climate change is emerging as a profoundly traumatic event, particularly considering human culture's continuity (Brulle & Norgaard 2019). Reparation is a necessary but not sufficient part of healing from trauma (Danieli 2009: 41–77). Reparations must both reduce carbon emissions and address their historical dimensions while also delivering adaptation and resilience to safeguard life.

An example of events that can inspire reparation thought in climate change adaptation is the legal struggle of indigenous peoples who suffered Canada's residential schools policy—a series of human rights violations committed over 150 years. Mahoney (2019: 207) explains that indigenous law 'framed the wide range of harms, empowered the victims to articulate what they wanted, justified individual and collective reparations, and laid the groundwork for a new relationship with the perpetrators' in the reparations in the Indian Residential School Settlement Agreement. Indigenous law provided an alternative to a colonial model of negotiation based on the principle of corrective justice. First Nations proposed instead measures rooted in indigenous law, such as restorative actions, the recognition of intergenerational harms, and establishing a truth commission (Mahoney 2019). The implications spread in time:

> Reparation looks forward, signalling not only the concern of victims and survivors with monetary compensation but, just as importantly—as the word's root, 'repair,' indicates—with upholding dignity and recovering health in the wake of gross violations of human rights (Bonner & James 2011).

By embracing reparative innovation in climate adaptation, we seek to bring these insights into approaches to address human vulnerabilities through knowledge-making and innovation.

Queer studies embrace a reparative impulse to enable positive attachments within a culture that rejects part of its members. Cultural theorist Eve Kosofsky Sedgwick interrogated the link between learning and positive outcomes. Sedgwick concluded that reparative impulses support people and communities to gain sustenance even within cultures that do not sustain them (Sedgwick 2003). Against criticisms that seek to anticipate the hidden meaning of everything, reparative readings situate the object of knowledge within a material history of multiple experiences and attachments (see also Hanson 2011, Wiegman 2014). We propose to rethink adaptation innovations as reparative both to accept the horrors of climate change and to provide a hopeful response to this urgent crisis. There are examples of how queer solidarities support urban resilience and responses to disasters that recognise all citizens as active agents rather than passive vulnerable groups (Wisner *et al.* 2017). With this paper we aim to extend this scholarship by redeploying the notion of reparation in the context of innovation for climate adaptation.

However, what such a reparative impulse could look like in the field of climate adaptation is not entirely clear. Here we propose to think of a reparative framework in relation to one of the most popular ideas to think about environmental innovation: disruptive innovation.

Reparative innovation as an alternative to disruptive innovation

The concept of reparative innovation emerges in stark contrast with a better understood concept of disruptive innovation. Disruptive innovation seeks to alter a given market and technological context radically. The concept derives from the notion of creative destruction (Schumpeter 1942), which assumes that invention acts as a disruptive force that creates renewal (and 'progress') in economic systems. Entrepreneurs and inventors become agents of change, driving change throughout industries and society. Sustaining innovations introduce change incrementally. In contrast, disruptive innovations are low-cost, accessible technologies that produce sweeping and fundamental changes across markets (Christensen 2013). They establish new value propositions, change consumer behaviors, and displace incumbent firms. The concept of disruptive innovation emerged from a concern with strategic management options for corporations. According to an influential interpretation by Abernathy and Clark (1985), disruptive technologies are characterised by their qualitative differences in associated skill sets, resources, and competencies compared with established technologies. Thus, their diffusion and establishment render entire industrial systems obsolete.

The concept of disruptive innovation tends to have a narrow focus of technological change and may not always acknowledge the variety of ways in which innovation occurs (Markides 2006, McDowall 2018). Nevertheless, the idea of disruptive technology remains influential and widely used. It has become framed as a source of 'simpler, cheaper, easier to use' solutions that may effectively tackle pervasive social issues such as poverty or sustainability (Hart 2005). The emergence of new digital technologies has reignited disruptive innovation ideas to tackle resilience and sustainability problems (Nasiri *et al.* 2017, World Bank 2018). Likewise, disruptive innovation ideas inform research on business innovation and sustainability (Cohen & Winn 2007, Dean & McMullen 2007) and support the argument of mass-market transformations propelled by sustainable business models (Aminoff *et al.* 2017, Schaltegger *et al.* 2016).

In science and technology studies, disruptive innovations interrupt the operation of socio-technical systems, forcing a change in the configuration of social practices and material technologies. Socio-technological configurations appear as a regime that is semi-stable for the analyst. A transition happens when disruptive innovations find their way into that regime, forcing a realignment of social and material components. Crucial to these analyses is that disruption can be seen as a 'prerequisite of system reconfiguration', rendering the dynamic indispensable to transition processes (Kivimaa *et al.* 2021). Niche innovations can only be radical enough if driven by disruptive innovations that hold power to overthrow unsustainable socio-technical regimes (e.g., Johnstone *et al.* 2020, Tyfield 2011).

Transition scholars argue that disruptive innovation fosters sustainability transitions. For example, renewable energy technologies are frequently framed as disruptive innovations that may challenge fossil-fuel-dependent production and consumption systems. Disruptive innovations in solar energy, for example, include customer-oriented solutions for batteries and photovoltaic (PV) power (Frankel & Wagner 2017, Say *et al.* 2018), solar utilities (Eisen 2010), or PV systems (Frankel *et al.* 2014). But the range of disruptive innovations in the current infrastructure regime is varied, ranging from hydrogen fuel cells (Hardman *et al.* 2013) to sharing economy solutions (Schneider 2017). While these arguments are more familiar in debates about reducing carbon emissions, they are gaining traction in adaptation research concerning the disruptive force required to achieve resilience and transformation (Saxena *et al.* 2018). These connections become increasingly apparent in innovations that address mitigation and adaptation simultaneously: for example, off-grid renewable technologies (Sapkota *et al.* 2014) or flexible and modular infrastructure designs (Shakou *et al.* 2019).

While disruptive innovations may have a place in urban adaptation, a fundamental insight from transitions theory is that such disruptive innovations emerge within the dominant socio-technical system, and, hence, they do not necessarily challenge it (Bulkeley *et al.* 2014). The concept of disruptive innovation emerged from an interest in understanding incumbent strategies to manage threats from new technologies. The ensuing frameworks have remained geared towards analyses of industrial dynamics and changes in markets. Disruptive innovations are embedded in the incumbent's grammar (and, even more deeply, in the logic of political economies and the global capitalist system). In that sense, the promise of disruption is misleading. Changing the system fundamentally is not the objective of disruptive technology. In summary, the link between abstract ideas of disruptive innovation and the question of urban resilience is fraught. Reparative innovation provides an alternative angle of looking, a different way of engaging with the question of innovation that may be more attuned to the demands of adaptation in urban areas.

Finding hope in the reparative

Unlike narratives of disruptive innovation, reparative innovations emerge from a profound recognition of specific social and cultural histories—including hegemonic narratives of capitalist extractivism and colonial domination—that shape the context of adaptation action. In urban environments, adaptation depends on the interactions with multiple infrastructure systems and variegated impacts of different types of disasters, from heat to flooding (Gough *et al.* 2019). Urban infrastructure landscapes are constituted through governance cultures, resource flows, and everyday life practices (Castán Broto 2019). Infrastructure is implicated in urban resilience and the creation of livable urban spaces in complex ways (Petrescu *et al.* 2020). It shapes urban practices at different levels:

> Infrastructure is food production and the social–technical relationships that it entails. Infrastructure is about the ways in which seeds and credit circulate and how water is distributed; it is about how planting and harvesting are practised; it is about who can grow what where, about who is able to make a call on land for the purposes of food growing. Infrastructure is always part of a bigger matrix, as this and a number of other projects reveal. What exactly infrastructure connects and how it does so are important questions that can be answered contextually (Knowles 2019: 5).

From this reading, reparative innovations emerge as embedded in collective urban histories. Urban histories are not linear but complex and multilayered, as people's lives intersect in different planes, alongside ecosystems and technologies. Reparative technologies first acknowledge those socio-ecological, profoundly material, histories as a means to draw the space of innovation. Through experimentation with those landscapes, a wide range of adaptation possibilities emerges, linked in every case to situated perceptions of a place and its history.

Nevertheless, there is increasingly a consensus that adaptation depends on large societal transformations (Patterson *et al.* 2017), transformations dependent on multiple social and technological innovations and with likely uneven impacts in urban environments. Transition theory and ideas of disruptive innovations have been used to understand such transformations (Dixon *et al.* 2014). However, transition theory does not account for the spatial conditions of innovation and technological 'disruption'. Whether a given technology will suit an urban environment depends on multiple conditions of urban governance, the history of the city and its imprint in the built environment, and the cultural and social practices of technological use (Huang & Castán Broto 2018).

For example, a recent study compared how people reconstructed their houses after Typhoon Haiyan landed in Central Philippines in 2013 and after the Gorkha Earthquake in Nepal in 2015. The study casts self-recovery as inevitable and a process that can be harnessed to build resilience (Schofield *et al.* 2019). However, policy and planning can work against bottom-up efforts to build urban resilience. The comparative study mentioned above found that policy decisions to improve housing safety often had negative consequences for people's lives. Resettlement decisions separated families from the crucial networks that supported their livelihoods. Conditional cash grants raised prices, reducing the affordability of construction materials and labour.

Adaptation calls for nimbler technologies adapted to specific conditions and policies that recognise the trajectories in which adaptation occurs. Ideas of transition and associated accounts of disruptive innovation do not provide a spatially sensitive version of technological change in urban areas. Reparative innovation, as we explain below, seeks to engage with the existing capacities of a given place, assembling resources at hand to create new possibilities for adaptation.

Reparative innovation endorses an alternative reading of the process of change, one that recognises radical change as the unexpected product of long-term, uncoordinated shifts. In the project Low Carbon Action in Ordinary Cities, funded by the European Research Council, we are currently compiling examples of what such reparative innovations look like. In the infrastructure context of less developed urban areas, where informality is the norm, reparative innovation calls for positive imaginations of collective urban futures that also acknowledge difficult histories of colonial exploitation and resource extractivism.

In the city of Tasikmalaya in Indonesia, farmers make waterwheels out of bamboo to cope with drought. The bamboo waterwheels function to drive water from a local river to the withering farms. Tasikmalaya has a long tradition of bamboo culture, represented by the bamboo weaving crafts (Triharini 2014). As a native material, bamboo is widely used by local people in social practices such as building houses and making furniture. In this case, with extremely limited resources, local farmers use the native material to reduce drought impacts. This is a practice that involves craftsmanship as a means for ecological restoration. Rather than revolutionise water management, the challenge is integrating human skills and natural materials to manage the changing patterns of drought. Bamboo craft is physical but also culturally embedded in traditional techniques and a rich heritage of weaving patterns. There is a fundamental emotional component that accompanies bamboo craftsmanship, and that becomes embedded in local adaptation practices. What is the adaptation value of such practice? We hardly know because few evaluations consider this kind of craftsmanship as adaptation. Nevertheless, there is a promise in innovations that build resilience incrementally.

Reparative innovation follows material experimentation that emerges from a close reading of the urban landscape. In the city of Abakaliki in Nigeria, a young engineer named Anthony Okafor built a solar-powered tricycle. Known locally as Keke Napep, the tricycle is one of the most widely used means of transportation in Nigeria. Commonly powered by petrol or diesel, Keke Napep is highly polluting and dangerous. In this case, the young engineer's innovation of a solar-powered Keke Napep is reparative—building on the possibilities of a given context. As Keke Napep is central to local people's commuting practices, a solar-powered one could constitute a nimble solution to facilitate mobility. Moreover, a solar-powered Keke Napep can reconfigure multiple layers of operation of transport systems, as charging—rather than fueling—

becomes the primary demand. This reconfiguration does not need to be disruptive, market oriented, or policy driven.

Financialisation and the securitisation of urban spaces at the expense of vulnerable populations are increasingly the dominant accounts of climate change adaptation in urban areas. However, adaptation is most urgent in informal settlements lacking infrastructure, where disasters are compounded with structural inequalities. Innovations will no doubt be needed to catalyse a transformation to urban resilience. However, their eventual impacts will depend not only on the innovations themselves but also on how the innovation processes are conceived. This essay presents the idea of reparative innovation to rethink alternatives for urban adaptation that, rather than disrupting existing infrastructure systems, seek to engage with the political possibilities of situated knowledges and ecologies.

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