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A review

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Spatial inequalities and cities: A review

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Abstract

This special issue of Environment and Planning B focuses on Spatial Inequalities and Cities. As the world progresses to almost a fully urban state, locations, networks, and access shape the everyday lives lived in cities, alongside being the movers and shapers of the future of sustainable and equitable urbanization. This special issue brings together a set of peer-reviewerd papers spanning urban science, urban analytics, geographic information / spatial science, network science, and quantitative socio-economic-spatial analysis, to explore and examine how the morphological, structural and spatial form of cities is linked to the production, maintenance and exacerbation of socio-economic inequalities and injustices. The issue also presents a critical angle on data, methods, and their use, and on how novel data and methods can help shed light on new dimensions of spatial inequalities. This editorial presents a brief critical review of the field of urban spatial inequalities and a summary of the special issue.

Keywords

Disparity, inequality, injustice, cities, location, mobility, urban structure, networks, infrastructure, complexity

Introduction: Cities and Inequality

The United Nations (UN) predicts that by 2050, 68% of the world's projected 9.5 billion people will be living in urban areas (United Nations, 2018). On the one hand, cities of all sizes continue to grow, fuelled by the unabated concentration of employment, amenities, and opportunities in cities (United Nations, 2020). On the other hand, the concentration of wealth and income growth at the top means that economic inequalities have widened (Piketty, 2014), which translates in evermore uneven

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competition for limited urban resources. Who is located *where* in space determines *what* they have access to and *how* they live. Cities and inequalities are tightly intertwined, and the coupling is intensely accelerated, as the planet becomes almost fully urban (Cottineau and Pumain, 2022).

Not all inequalities are equally concerning. Indeed, the city itself is the result of a process that produces an inequality in space: agglomeration economies and increasing returns to scale produce a concentration of human populations and differentiate a dense city area from its sparse hinterland. Cities attract and generate diverse profiles of residents, activities, and environments. Cities are the seat to an increasing share of economic activity. They allow specialisation and diversity to emerge through economic and social interdependence. This contributes to the creation of wealth, ideas and technological innovation.

But cities are also drivers of actuating the sharpest levels human and socio-economic inequalities, inequalities which grow over time and can fuel legitimate feelings of injustice (Florida, 2017; Hamnett, 2019; Harvey, 1973; Piketty, 2014; Sarkar, 2019; Sarkar et al., 2018). Furthermore, cities act as spatial sorting filters: two persons could be equal from the socio-economic perspective (e.g. on equal incomes or wages), but could still experience unequal access to urban resources, services, infrastructure, and amenities depending on where they live in the city. Thus, their real incomes differ, depending on where they live. Over time, the spatial form of the city shapes access, which can exacerbate inequalities.

While inequalities between countries have declined, inequalities within countries have risen sharply, in complex ways, and about 71% of the world population lives in countries where inequalities have risen (United Nations, 2020bib_united_nations_u_2020). These increased levels of intra-national inequalities result from intra-metropolitan inequalities (OECD, 2016) as well as increased inequalities between urban and non-urban spaces and inequalities between cities.

Acknowledging the tight connection between urbanisation and social, economic, and spatial inequalities, what is it about cities that so fundamentally interacts with, produces, or maintains inequalities? Is it their size? Their form and densities? Their morphologies over time? Their infrastructure? Their networks? Their flows? In this special issue, we called for papers to address the connections between these spatial, formal, and geographical characteristics of cities and inequalities.

The measurement, mapping, and tracking of inequalities is not only of critical importance to the science of cities but also to current and future urban planning and policy making. While inequalities frequently occur in the economic, social, or technological space, they are most apparent in physical space. By *socio-economic inequalities* (Sen and Foster, 1997), we mean inequalities in the distributions of resources, access, and opportunities between *persons*. Such inequalities are distinguished from *spatial*, *urban,* or *geographic inequalities*. This latter class of inequalities derives from the physical, morphological, topographical, connectivity and relational aspect of space, and how it affects the distributions of resources, access, and opportunities between *areas* or *places*, with the socio-economic inequalities, at least in part, *arising as a consequence* between sets of people who inhabit different locations in space (Cottineau and Vallee, 2022).

While the measurement of economic, social, and technological inequalities has received much attention in social science research, the spatial embedding of inequalities has not received its due attention, even when the request to do so formally went out as early as Harvey (1973). While the qualitative relationship between distributive and procedural inequalities in geographic space and their inherent relationship to justice outcomes is loud and clear (Fanstein, 2010; Harvey, 1973; Soja, 2010), and while the rigorous science behind the measurement and mapping of socio-economic inequalities is strong (Atkinson, 2015; Piketty, 2014; Sen and Foster, 1997), the attention paid to the theory, measurement and mapping of *spatial inequalities* has remained scant. Most areas of academic research conceptualize, measure, and understand inequalities, as a-spatial and a-geographic. This special issue is motivated by the aim of focussing precisely on the spatial-geographic

dimension in how inequalities play out in urban space, and to identify and organise what it is about cities that fuels inequalities.

The recent outbreak of COVID-19 has brought this out even more acutely by making it a life or death question: indeed, the world has witnessed how lower income, economically and socially vulnerable communities have suffered the consequences of cities that are not safe, not resilient, not inclusive, and not sustainable. Ultimately, their hardship and suffering was as much a function of *where they were (or could not be)* and *what they could access (or could not)* as it was a function of *how much they had (or didn't have)*.

Dimensions of spatial urban inequalities

Cities are, at their core, built and technological/digital environments inhabited by people. The texture of the environment can both reveal social stratification among urban inhabitants (Abascal et al., 2022) and also lead to the continual (re)structuring of urban societies (Talen, 2018).

In this section, we move to broadly conceive of how we can organise knowledge on the measurement of spatial and geographic inequalities, by encoding urban geography into three dimensions:

- Inequalities by location: city size, scale, place, urban form, and morphology.
- Inequalities by movement: transport networks, network dynamics, mobility, and accessibility.
- Inequalities by larger infrastructural systems: urban infrastructure (housing stock, water, electricity, Internet, etc.), their dynamics, management, and access.

We then look at their relationships with the social, environmental, health, or economic inequalities that occur as outcomes, or that in turn affect the evolution of the urban dimension in question, in any part of the urban world.

Location: Form and size

Urban form refers to the spatial configuration of inhabited spaces within cities, usually described by the distribution of densities of the built environment and/or density of people and activities. Urban forms at the city scale tend to be clustered into three models or typologies: the monocentric city, the polycentric city and the dispersed, many-centre or no-centre city, using measures of sprawl (such as elongation or compactness, cf. Haggett (1965)) and centricity (rank-size slope, Moran's I, cf. Batty (2001); Tsai (2005); Sarkar et al. (2020b)). These typical urban forms and the continuum of in-between configurations provide referentials to position cities and their trajectories as their joint distributions of jobs and housing evolve. For example, as cities grow, it may become progressively inefficient to have a single monocentric centre for all economic activity (as most models since Alonso's assume), as residents would need to travel longer distances to access the centre, which might then lead to exacerbated inequalities via spatial sorting through the housing market (Sarkar et al., 2021a). In policy debates, therefore, polycentricity becomes a normative aim, with '30-minute' cities and '15-minute' neighbourhoods being proposed towards a more efficient urban form.

The density profiles of cities also have an influence on the social and environmental conditions of their residents. Low density sprawled urban forms with detached housing are associated with a higher reliance on private transportation, which fosters higher energy consumption than high to medium density apartment or terrace/townhouse living, public, shared, or active transportation modes, more available in compact cities. Moreover, how residents, buildings, and activities are distributed within a city can impact the inequalities faced by residents in terms of other dimensions

such as energy consumption, health and education accessibility, pollution, or segregation. For example, urban planning and residential segregation in the United States have created a paradox whereby, in Los Angeles, 'all else equal, tracts whose residents drive less are exposed to more air pollution' (Boeing et al., 2023). In terms of leisure inequalities, 'the reasons for modest households to travel are less varied': low-income households tend to restrain leisure trips to keep affording the necessary commuting trips (Jouffe et al., 2019). In terms of health inequalities, urban form and urban size seem to play a role through the medium of segregation and accessibility to health food supply and medical services. Authors have shown that residential segregation mattered for the availability of fruits, vegetables and health foods (Morland and Filomena, 2007; Stella et al., 2014; Goodman et al., 2018; Havewala, 2021), whereas differential accessibility to green spaces informed inequities ranging from pollution to stress and children development (Liu et al., 2021; Tao et al., 2021).

Urban size refers to the aggregate dimension of cities, usually approached by the total number of residents, households, jobs or urbanised area. The analysis of its non-linear effects on urban features and inequalities follows the idea that 'more is different'. In a nutshell, large cities allow for the segmentation and specialisation of urban societies into more diverse, productive, and innovative urban societies, realising economies of scale produced on physical infrastructure and positive returns to scale in terms of creative interactions and matching processes (Pumain, 2004; Bettencourt, 2013). However, they also create disproportionately more income and housing inequalities (Cottineau et al., 2019; Heinrich Mora et al., 2021; Pan et al., 2016; Sarkar, 2019; Sarkar et al., 2018; Shutters et al., 2022) and negative externalities such as congestion (Louf and Barthelemy, 2014). Typically, the larger the city size, the more wealth is produced, but a disproportionately higher amount of this extra wealth goes to the highest income earners, which could drive up prices in the housing market, forcing moderate and lower income earners out.

Sassen (1991) proposed a sociological analysis of global cities connected through a tight network of financial links. She put forward the thesis of hour-glass societies created by the complementarity between high-skilled business services jobs and low-skilled personal services jobs. In other words, busy professionals in niche industries of global scope need support from low-wage workers, often migrants from the Global South, to care for their children, cater for their food and manage their homes. Extending the analysis to the rest of the urban hierarchy, Eeckhout et al. (2014); Sarkar et al. (2020a) found a stronger association between high-skill and low-skill workers in larger cities. Such cities, because of their economic specialisation in high-value industries with more high-skill workers, create an unequal workforce both in terms of education and wages. Another mechanism explaining the positive non-linear relationship between city-size and economic output is the differential return to skills in large versus small cities (Glaeser et al., 2011). Empirically, Sarkar et al. (2018); Sarkar (2019); Cottineau et al. (2019); Heinrich Mora et al. (2021) found evidence of a different scaling regime for income deciles in Australian, US, and French cities. In other words, richer households are represented more than proportionately in larger cities. For France, this is associated with a rising Gini index with city size, regardless of the definition of city chosen.

Movement: network structure, mobility dynamics, and accessibility

At any point in time, we are either *at* a particular point in space, or *moving* through space. What allows anything to flow or move, is *networks*. Networks of roads and transit provide the nervous system which describes the connectivity, topology, and geometry of how people, goods, vehicles, or indeed anything, moves through a city.

For a long time, urban form research was focused much more on *locations*, instead of *connectivity and flow* between locations. Consider, as example, that almost all historical models for urban structure have traditionally focused on the hierarchical organisation of space and location with

transport through space left as an implicit cost or constraint variable (Cottineau et al., 2024). But as Batty (2013) notes: '*cities must now be looked at as constellations of interactions, communications, relations, flows, and networks, rather than as locations, and argue that location is, in effect, a synthesis of interactions: indeed, this concept lies at the basis of our new science'.*

The primary reason why the network structure of roads and transit pathways is a fundamental variable affecting inequalities is *accessibility.* Accessibility is defined as *the ease of reaching a destination*, and affects how far, how long, and at what cost a person must travel in order to reach a desired destination (Levinson, 1998). A destination is more desirable if it offers more opportunities (e.g. jobs, leisure, urban community, and social infrastructure), and accessibility is higher if these opportunities can be reached with lower distances, lower travel times or lower costs of travel. If either of the components, opportunities or the distance/time/cost of travel to these opportunities, is unequally distributed, it actuates inequalities in terms of who can access what in the city.

Cities around the world show differences in the ways inequalities of access over networks emerge and take shape. In Australian cities, inequalities of access are tightly linked to how socio-economic classes organise in space. High-income and very-high-income earners cluster into tight spatial groups. The most affluent areas – the high-value residential neighbourhoods – are closest spatially to the areas where there are the highest number of jobs as well as having the most dense and diverse transit and active transport opportunities. This results in a labour market where the highest-income earners travel fastest and pay the least to access jobs and other opportunities, whereas lower-income and moderate-income earners are forced out to the peripheries of the cities and must therefore travel as well as pay more to access these same opportunities. But, in Canadian cities, a somewhat different perspective emerges: lower income workers travel slower, and cover smaller distances (Cui et al., 2019). Here, the inequalities arise from not being able to access better opportunities that may be at longer distances, and from not being able to travel faster or longer distances. In the UK, lower socio-economic and vulnerable groups, including women, living in transport poor areas face barriers in accessing public transport options, and are forced to turn down employment options due to transport limitations or unaffordability (Gates et al., 2019), and continue to be trapped in isolated neighbourhoods with high levels of deprivation, cut off from larger labour markets that disproportionately benefit higher income residents who are better connected to these opportunities (Rae et al., 2016).

Inequalities of access also arise out of uneven spatial distributions of social and community infrastructure, and disparities in spatial distributions of transit networks, schedules and network service frequencies. For example, in major Australian cities, greenfield development areas lag significantly behind the regional average access to transit networks and social and community infrastructure as compared to inner city and Central Business District areas (Sarkar et al., 2021b). In the US, significantly higher levels of investment into building and maintaining road networks funnels money away from public transportation development, resulting in a disproportional advantage to higher income earners, who are more likely to own cars, and enjoy shorter commutes to jobs and other opportunities, vis-à-vis lower income earners dependent on public transport options, who face longer commutes and barriers to accessing jobs and opportunities (Sen, 2022). But, empirical evidence strongly suggests exactly the opposite policy response: investing more in transit networks and public transport network development options could lead to more compact and sustainable network and urban structure futures. Locations with high transit accessibility consistently have more riders and higher residential density, and transit systems that provide greater accessibility and with a larger base for patronage have proportionally greater ridership increase per unit of accessibility (Wu et al., 2019).

Thus, overall, how networks are shaped, and how the dynamics of services, scheduling, and frequencies are planned, and how neighbourhoods, jobs, and housing distributions are planned in tandem with networks, have a critical and fundamental role in either countering or exacerbating inequalities between socio-economic groups through the dynamics of access and mobility.

Larger infrastructural systems

Finally, the spatial distributions of many important urban infrastructures and access to urban amenities can themselves create compounding inequalities between people or groups. In this context, we refer to *infrastructure* generally, referring to any aspect of the built environment that facilitates urban life, such as housing, transit, environmental management, food, or energy, while an *amenity* refers to a specific facility, such an apartment complex, a subway stop, a culvert, a restaurant, or a power station. The distributions of infrastructure types are rarely independent, and their functions often interact. One excellent example of this is the 'circular logic' of transit-oriented development (Qviström et al., 2019). New public transit infrastructure in a place often increases the desirability of a location for private investment in housing. This, in turn, tends to increase the population near public transit infrastructure, which then increases demand for additional transit infrastructure and other secondary infrastructure. This effect works in the *other* direction as well (Hackworth, 2016), as changes to some urban infrastructures *reduce* the future demand for (or capacity of) other infrastructure. Thus, the patterns of affordable housing and transit infrastructure or public investment often coincide, reinforcing one another in the present moment, but also creating cycles of persistent (dis)investment.

These multiple different dimensions of urban inequality due to unequal infrastructure and access have been studied for a very long time (Booth and Reeder, 1889), but still new thinking is changing how we approach these co-occurrences in cities. First, the concept of *deprivation*, well-defined by Townsend (1987) to encompass the many relative disadvantages that people face in their local communities, has provided a stable conceptual underpinning for much past work seeking to understand the spatial co-location of urban infrastructure and amenities. This might indicate, for example, mutually reinforcing differences in peoples' ability to service their energy needs for housing and transit Robinson and Mattioli (2020) or for their health and their housing quality (Macintyre et al., 1993). Alternatively, an emerging literature in urban public health focuses on the intersectional nature of deprivation (Bambra, 2022), suggesting that the many dimensions of individuals' social identities must be studied together, rather than separately by race, class, or gender. One clear example Bittencourt et al. (2021) shows the intersectional effects of class and race on urban access to employment, seeking to estimate different effects for each distinct class-race combination. The core difference in this sense is the idea that the various axes of individual experience and unequal investment in urban infrastructure may interact in nonlinear, multiplicative, or even idiosyncratic ways. The complexity of these intersectional processes (and their methodological requirements (Bell et al., 2019)) make them particularly tricky to understand. Hence, more work applying formal intersectional analysis techniques are necessary to understand these complex co-occurences of urban inequality due to infrastructure and access to amenity.

In this special issue

We put out the call seeking papers that employ pertinent and relevant data sets to bring out empirical observations, and/or model related processes and their outcomes, or any combination of analytics, comparative, and/or simulation techniques. Further, papers that could relate the findings from empirical, model based, or computational studies to reflect actively on, critique, or inform planning principles and policy in relevant national contexts were highly welcomed. Throughout, our focus on the *spatial* and *geographic* dimension was made very clear to all contributors.

Eventually, 17 articles were selected to figure on this special issue on the topic of urban inequalities. Because of this relatively large number, Table 1 gathers the details of the contributions selected in terms of data, methods, geography, and main takeaways. In this editorial, we focus on the overall presentation of the articles. They are testament to the fact that this concept is very broad and

Table 1. Summary of Papers in the special issue on Urban Spatial Inequalities.

First Author, Title, DOI	Data and time	Geography	Methods	Dimension of inequality: Summary
Knaap, segregated by design? Street network topological structure and the measurement of urban segregation, 10.1177/2399808323197956	OSM, 2013-2017	US (380 metropolitan core based statistical areas)	Segregation and network metrics over road networks	Disparities, networks, movement, segregation: Segregation patterns are highly correlated with network metrics, and networks shape segregation
Collins, spatiotemporal gender differences in urban vibrancy, 10.1177/23998083231209073	ISTAT decennial census, call detail record (CDR) from Gruppo TIM, OSM, 2011/2017	Italy (Milan, Rome, Turin, Naples, Venice, Palermo, Bari)	Spatial Error models (SEM) spatial lag models (SAR)	Disparity, urban vibrancy and gender segregation: Third places are associated with the largest gender inequality in urban presence
Janatabadi, Unravelling transit service and land use components of the socio-spatial inequality of access, 10.1177/23998083231207534	ACS, LEHD, OSM, 2019	US (Washington DC)	Indicators based on accessibility measures and Bi-variate local indicator of spatial autocorrelation	Injustice, transit accessibility and effects on vulnerable groups: Transit service access is worse off than jobs distribution, carless and low income households reside near better transit service areas, African Americans face more discrimination on both transit service access as well as jobs distribution
Calafiore, inequalities in experiencing urban functions. An exploration of human digital (geo-) footprints, 10.1177/239980832312085	GPS trajectories from spectus.ai, census – index of multiple deprivation (2019)	Great Britain (UK excluding Northern Ireland)	Trajectory motif construction	Inequality, networks, movement: People who live in a given 'kind of area' will move between similar 'kinds of areas' over their day, and this reflects urban functional segregation
Peris, Proximity or opportunity? Spatial and market determinants of private individuals' buy-to-let investments, 10.1177/23998083231217014	Microdata from tax registers, 2010-2018	France (Paris, Lyon, Avignon)	Spatial interaction models with adaptive zoning	Disparities, wealth accumulation through real-estate investment: Investing in upmarket areas and safety of investment are key factors shaping housing wealth accumulation by private individuals

(continued)

Table 1. (continued)

First Author, Title, DOI	Data and time	Geography	Methods	Dimension of inequality: Summary
Iyer, mobility and transit segregation in urban spaces, 10.1177/23998083231219294	ACS (Table B19001), mobility data from SafeGraph, GTFS, OSM, 2020-2021	US (16 cities)	Segregation measures and network metrics	Inequality, networks, movement, segregation: Segregation should be considered from multiple perspectives, and not just neighbourhood segregation, when planning for transit systems and amenity locational planning, and local neighbourhood planning
Lopes, Evaluating the impact of social housing policies: Measuring accessibility changes when individuals move to social housing projects, 10.1177/23998083231218774	ANTP 2020, OSM, google Maps, SEHARPE, notary's office, Federal public records, street network (MUsA), bus timetable (STTU), 2009-2017	Brazil (Natal)	Access analysis on uni- and multi-modal transport network model	Inequality, centrality, transportation network and access: Low income beneficiaries of housing program experience the largest loss of accessibility
Gao, Unpacking urban scaling and socio-spatial inequalities in mobility: Evidence from England, 10.1177/23998083241234137	Mobile phone user data, socio-economic census data, index of deprivation, 2017, 2019	England (109 major towns and cities)	Urban scaling analysis	Disparities, city size, scale: Larger cities are associated with greater social interactions, particularly among socio-economically advantaged groups. However, they also exhibit exacerbated self-segregation, particularly amongst the most deprived groups
Verma, Regional comparison of socio-demographic variation in urban E-scooter usage, 10.1177/23998083241240195	ACS, E-scooter stock and trips data from scooter companies, National Walkability index data from US-EPA, 2019	US (Washington DC, Portland, Atlanta)	MESF Regression, along with spatial autocorrelation analysis using Moran's I and VIF	Inequality, micromobility, active transport: General variations in e-scooter usage based on gender, income, and race, marginal and vulnerable groups especially black and Hispanic populations remain underserved

(continued)

Table 1. (continued)

First Author, Title, DOI	Data and time	Geography	Methods	Dimension of inequality: Summary
Bottoms, Towards urban place-based resilience modelling: Mixed methods for a flood resilience assessment index, 10.1177/23998083241243104	Census, HUD homelessness, CFPB credit scores, OSM + ORNL + Microsoft buildings + OSM drivetimes, CDC mental wellbeing, MIT elections, US DOE, 2019-2020	US (5 counties)	Index construction using dasymetric refinement	Injustice, land use and amenities locational planning: Prioritizing place-based, history informed, and ethnographic measures of resilience is imperative to move towards structural change in response and recovery systems for flooding and other natural disasters
Maffini, inequalities in the potential movement of social groups: A network-based indicator, 10.1177/23998083241246375	Census data, IBGE, OSM, 2010	Brazil (Santa Maria and Pelotas)	centrality, betweenness, movement analysis on network models	Inequality, access, movement, networks: High income groups have to travel lower distances to work, being mostly located around the CBD, whereas low socio-economic groups are more dispersed, suburbanised, and have to travel longer distances to work. Use what-if scenarios in planning to address these inequalities before they arise
Pons, The fuel of discontent? Transport poverty risks and equity concerns in French urban peripheries, 10.1177/23998083241246377	Microdata on households and jobs, travel times, 2019	France, Lyon	Access, poverty and welfare measurement	Injustice, transit access to jobs, transport and energy poverty: Transport and energy poverty can combine to produce outcomes like loss of employment and constrain the adaptive capacity of poor households. Policy should focus on improving public infrastructure, increasing access to transportation options, addressing issues such as job precariousness or housing

(continued)

Table 1. (continued)

First Author, Title, DOI	Data and time	Geography	Methods	Dimension of inequality: Summary
Cohen, How accessible are cities for visually impaired pedestrians? A case of greater London	OSM street network and POIs	Local and global accessibility of street segments and shortest paths	UK (London)	Inequality, effect of visual landmarks, path complexity, crowding and road hierarchy on accessibility of visually impaired pedestrians to the road network: Areas are more accessible when non-accessible streets are short, sporadic and clustered, when there are fewer green spaces and non-residential areas
Silva, inequality and spatial mismatch in the urban labour market: Evidence for the metropolitan area of Curitiba, Brazil	Travel time data from Google Maps distance Matrix API (2018), Annual social information report (RAIS) database from the Brazilian Ministry of Labor (2017), Origin and destination (OD) survey of Curitiba (2017)	Brazil (Curitiba)	Dissimilarity index of accessibility, econometric regression analysis	Inequality, morphology and effect on accessibility of workers: Concentrated pockets of inaccessibility make it difficult for people in low-income areas to access jobs
Sulis, Who can access what? Uncovering urban inequality in access to service for senior citizens	Local data from the three cities, Ookla Speedtest data, google Maps based POIs, 2019-2020	Europe (Amsterdam, Berlin, Paris)	Local spatial statistics, Shannon's entropy, unsupervised clustering	Injustice, accessibility and POI measurement and effects on senior citizens: Measurement of accessibility and POI-colocation at fine spatio-temporal scales must be employed for informing place and location based design for specific higher-need socio-economic groups
Ubareviciene, Exploring age-related patterns of residential mobility in different settlement systems: A comparative study of Estonia and Lithuania	Microdata about migration from linked censuses, 2011-2021	Lithuania and Estonia	Binary regression	Disparities, socio-demographic movement and urban structure: Challenging traditional views on migration, findings show that young adults have high likelihoods of migration towards urbanization, suburbanization, and counter-urbanization

(continued)

Table 1. (continued)

First Author, Title, DOI	Data and time	Geography	Methods	Dimension of inequality: Summary
Xu, New methods for old questions: Predicting Historical urban renewal areas in the United States	Microdata from historical censuses, historical boundaries, home values and household income, HOLC 'redlining' maps	US (50 cities), 1949–1970	Machine learning and Logistic regression	Disparities, urban change, and segregation: Race and housing age are significant determinants of urban renewal

Abbreviations used for data sources and methods: American Community Survey (ACS), Associacao Nacional de Transportes Publico (ANTP), Center for Disease Control and Prevention (CDC), Consumer Financial Protection Bureau (CFPB), Global Positioning System (GPS), General Transit Feed Specification (GTFS), Home-Owners Loan Corporation (HOLC), Housing and Urban Development (HUD), Brazilian Institute of Geography and Statistics (IBGE), Istituto Nazionale di Statistica (ISTAT), Longitudinal Employer Household Dynamics (LEHD), Moran Eigenvector Spatial Filtering (MESF), Massachusetts Institute of Technology (MIT), Morphology and Uses of the Architecture (MUsA), Oak Ridge National Laboratory (ORNL), Open Street Maps (OSM), POI (Points of Interest), Spatial Lag Models (SAR), Natal's housing department (SEHARPE), Spatial Error Models (SEM), Natal's department of transit (STTU), United States Department of Environment (US-DOE), United States Environmental Protection Agency (US-EPA).

encompasses many dimensions of inequality and many dimensions of urbanity, which can be analysed with a diversity of methods and lead to a variety of policy recommendations. In this section, we present and summarise the articles published in this special issue along those lines. The articles selected focus on nine countries (Figure 1) and several hundred cities, in Europe and the Americas. Authors of this special issue consider urban inequality as a dynamic process and therefore mostly use longitudinal or cross sectional analysis at multiple points in time. A long historical time frame is found in one article on urban regeneration in US cities (1949-1970) but for most papers, the analysis is restricted to one decade or less of the 21st century (Figure 2).

Data and methods

The special issue papers' tight focus on contemporary urban inequalities means that most of the papers leverage the same sources of data. Indeed, given the special issue's heavy focus on inequality and movement, many papers in the issue focus on mobility data from mobile phones and/or OpenStreetMap (OSM). Mobile phone data has served as a reliable 'new' data method for understanding observed mobility in society, although it still is affected by issues around sampling bias and misrepresentation. The ubiquity of OSM in this special issue highlights the two-way street linking data and analysis. Without OSM, much of urban analytics would be impossible; yet, this also makes much of urban analytics *difficult* to extend beyond the bounds of OSM as it exists today. For example, street networks and transport systems in the developing part of the world are only partially and mostly inaccurately mapped in OSM. Thus, even when we need critical inequalities research urgently for the poorer or developing parts of the world, the unavailability of good data from open public sources like the OSM restricts this much needed research. What the OSM project calls 'attic data', the older representations of existing entities, are not intended to provide a complete representation of the past but rather a presentation of what *OSM would have looked like* in the past. Things not tracked today have no clear route to representation in OSM, although they may be archived by aligned projects such as OpenHistoricalMap.

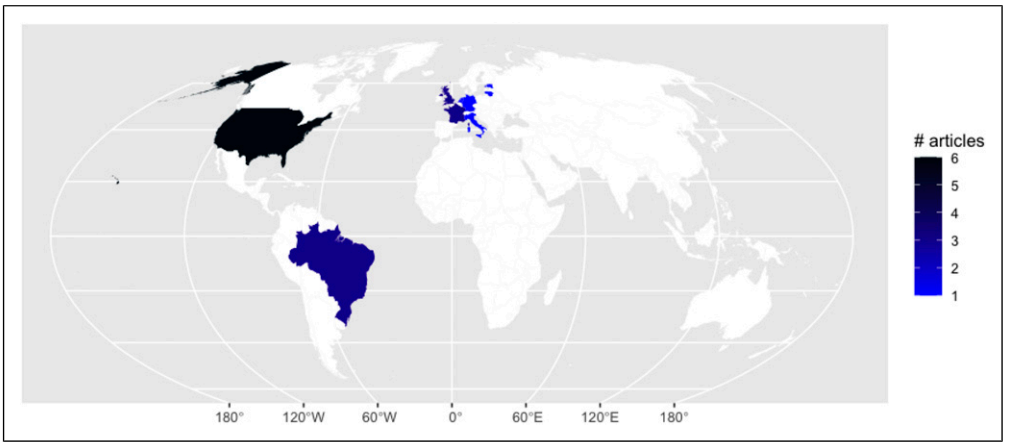

Figure 1. Geographical coverage of articles included in the special Issue.

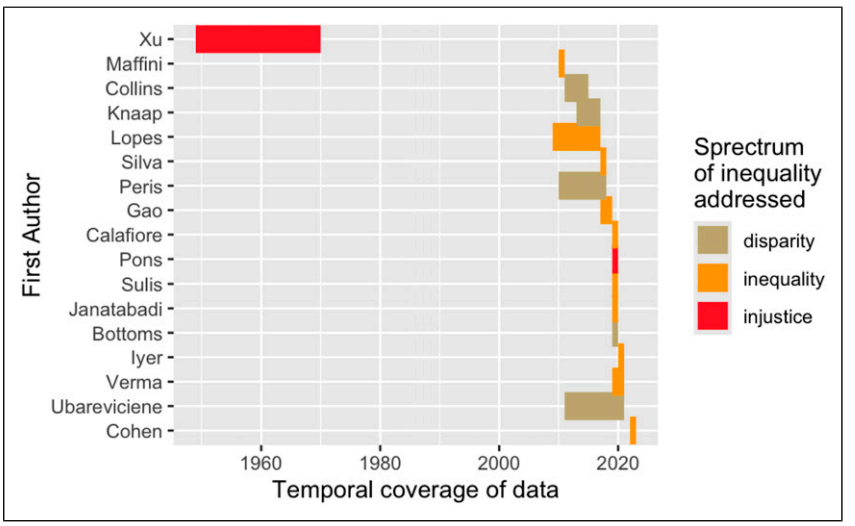

Figure 2. Temporal coverage of articles included in the special issue and position on the inequality spectrum.

Another data source commonly drawn upon was microdata, from official sources such as national census data or other administrative sources, which points the way towards future data innovations.

A wide diversity of methods, indicators, and measures was seen. A majority of the papers focused on segregation measures, regression analysis, exploratory spatial data analysis (ESDA), and accessibility analysis. Surprisingly, the use of machine learning (ML) is still very limited.

Spectrum of inequalities: from disparities to injustice

Urban inequalities refer to spatial and geographic configurations where a valuable resource is distributed such that places and spaces are unevenly endowed with it, or have uneven access to it, in a way that reflects or generates haves and have-nots, winners and losers, between population groups. Not all inequalities are of concern, and it is impossible to have an urban structure in which every

resource is uniformly distributed – indeed, there can exist no economic or social flow process in such a structure. So, at what point does an inequality become an inequality of concern in the sense of fairness or justice that leads to *lower social or spatial welfare*? In this special issue and in Figure 2 we identify a gradient of understanding of urban inequality which ranges from the positive description of geographical *disparities* (i.e. the spatial variation of a given variable) to the normative analysis of spatial *injustice* (i.e. the unfair distribution of resources leading to lower social or spatial welfare). Most articles in the issue address urban disparities and inequalities, but only a few papers formally focus on the social and spatial justice implications of disparities and inequalities, even though all papers either implicitly or explicitly are concerned with justice as a motivation for studying inequalities and disparities. We posit that in the future, if urban science is to make relevant and meaningful policy contributions, the theory, methods, and applications must increasingly move towards furthering the understanding of injustices that arise out of inequalities and disparities.

Conclusions and policy recommendations

Finally, the policy and recommendations dimensions in a majority of papers focussed on how urban structure and network interventions, redesign, and planning can positively influence segregation and accessibility. Several papers also focussed on how existing networks and urban structure can create or exacerbate inequalities. The basic notion coming through lies at the heart of the urban design and urban planning disciplines: the acknowledgement that altering the physical structure of cities, the built environment and the network structures, has an immense bearing on both the current and future lived experience and quality of life of individuals, and the collective systemic future of sustainability, liveability, and equity.

What's still missing? The future

This special issue was our effort to focus attention onto the critical connection between location, size, urban forms, spatial networks, and urban infrastructure on the one hand, and disparities, inequalities, and injustices on the other hand, as well as their dynamic interactions. A critical reflection on the state of the research so far reveals some emerging strengths, but also missing pieces and warning signs which pave the way for future research.

First, a number of new data sources are emerging in different parts of the world which have the capacity to enrich this line of research. Such data sets providing fine spatio-temporal information about people and places was not readily available only a few years ago, but the likelihood of them becoming increasingly more available is higher each day. Current and future data sources illustrate both challenges for replication in urban analytics dependent upon this open data, but also illustrate how the reach of our data commons might need to be broadened in order to support more detailed long-term analysis.

Second, this availability of data goes hand in hand with the enormous changes being triggered by technological innovations, for example, the role of AI and machine learning in the context of the rising Smart City. Given its rising and increasingly widespread use in other disciplines, we were expecting to see many ML-based contributions in this special issue, but this wasn't the case. There are both pros and cons to this. The use of ML will provide an increasingly efficient channel as larger and larger data sources become available for urban research. Thus, a future research agenda on the informed, nuanced use and development of ML would be very critical. However, since we are much more interested in inference and causal connections, rather than predictions, its judicious first-principles based use is most advisable – the use of ML as a black-box of off-the-shelf algorithms applied on data may actually harm rather than benefit urban science. While technological changes triggering massive physical re-organizations are unavoidable in some sense, the warning is that

there is a responsibility to ensure that the changes being triggered work towards more equitable and more sustainable outcomes rather than their unchecked rise leading to exacerbating current inequalities and injustices.

Third, a lion's share of current research is focused on novel methods, data, and the positive-objective measurement of disparities and inequalities. This is essential, timely, and fundamental to advancing our research. But, looking to the future, the normative side of urban analytics and city science must strengthen itself: we need a rigorous, scientifically informed basis towards defining, measuring and countering inequalities and injustice, and taking us towards cities which are just and sustainable, and continue to remain so in the long term. Further rigorous science on decision-making also needs to be developed, so as to incorporate how collective decision-making and political process (including public participation approaches) may be enabled towards shaping policy, interventions and regulations for equitable, just and sustainable cities.

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