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Conceptualizing Urban Inequalities as a Complex Socio-Technical Phenomenon

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The United Nations World Social Report (2020) reveals that more than two thirds of the world's population live in countries where urban inequalities have increased in the last three decades. While urban inequalities are traditionally characterized as an economic issue, scholars are increasingly applying methods from geospatial analysis to study them. In the context of these advancements, it remains unclear what underlying perspectives are guiding decisions to concentrate on certain aspects of urban inequalities, while potentially ignoring others. We address this gap by reviewing the literature centered on the geospatial analysis of urban inequalities and identify three predominant research lenses from accessibility, distribution, and policy and stakeholder perspectives. As a primary contribution of this article, we connect the perspectives with ideas drawn from complexity theory to develop an overarching socio-technical framework for how urban inequalities emerge over space and time. While traditional scientific frameworks seek to increase knowledge through causality, complexity science acknowledges the inherent challenges in defining, understanding and solving complex problems such as urban inequalities, which has profound implications for their representation, modeling and interpretation. We critically reflect on the framework through key relational themes and insights drawn from the literature and close with considerations for future research.

Introduction

High levels of inequality have consequences for the social and spatial organization of cities (Modai-Snir and van Ham 2018; Nijman and Wei 2020). Reducing inequalities, within and among countries, is a central tenet of the Sustainable Development Goals with almost every country in the world committing to try and achieve these goals by 2030. Highly unequal societies are less effective at reducing poverty than those with low levels of inequality. Disparities in health, education, and access to everyday social and economic resources, make it challenging for people to break out of the cycle of poverty, leading to the reproduction of disadvantage from one generation to the next (Nijman and Wei 2020; United Nations, 2020:4).

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Most of the discourse on inequalities has traditionally focused on economic inequality, relying on popular unidimensional economic indices based on income, thus advancing our knowledge of income inequality significantly (Yap, Cocina, and Levy 2021). However, there is growing recognition across the social sciences and public institutions in the development sector that inequalities are embedded within specific socio-spatial contexts with varying consequences for different population groups (Franklin et al. 2022). It is in cities that the inherent and rapid increase in social and spatial unevenness is most noticed (Cassiers and Kesteloot 2012). Scholars are studying urban inequalities across a broad range of thematic areas such as housing ownership (Madden and Marcuse 2016), accessibility to opportunities (Pereira et al. 2021; Giannotti, Tomasiello, and Bittencourt 2022), energy poverty (Robinson 2019), disparities in internet use (Singleton, Alexiou, and Savani 2020), digitization (Graham and Dittus 2022), and the analysis of policies for inclusive urban development (Faber 2021). Findings indicate that the cumulative impacts of inequalities unfold across many dimensions of well-being (social, economic, political, and environmental) and are fundamentally related to issues of spatial justice (Soja 2010). These advancements, supported by expansions in computational power and increased access to new data sources, emphasize that the distribution of resources and opportunities across urban territories are not always equal or equitable (Van Wee and Geurs 2011). Consequently, inequalities can no longer be perceived as independent from the geographies within which they are embedded.

Nevertheless, the choice of metrics, variables, and theoretical approaches within the geographical analysis of urban inequalities is not always clear. An emphasis on a specific set of singular indicators across separate dimensions, may bias the view with some measures indicating significant growth in the economy and progress in policymaking, while others highlight how the quality of life of several urban populations around the world is degrading (Sassen 2014). The focus may be, for example, on the cumulative effects of different socio-spatial processes over time (Musterd et al. 2017; Modai-Snir and van Ham 2018; Boschken 2022), potential outcomes of varying policy scenarios (Guerrero 2020), or the distribution of environmental impacts (Ruttenauer 2019). This indicates the existence of underlying conceptual perspectives which anchor decisions to concentrate on certain facets of urban inequalities or the next, while potentially ignoring others. Furthermore, it leads to questions in relation to how these perspectives may contribute to increased understanding of the deeper socio-technical and systemic processes which reproduce urban inequalities.

Within this article we argue for increased integration between the geographical analysis of urban inequalities and complexity science. Whilst many researchers recognize the value in linking geographical analysis with a complex systems approach (Batty 2003; Manson and O'Sullivan 2006; Zhong et al. 2014; Anderson and Dragićević 2020), little has been explicitly addressed in connecting them to advance research into the structural drivers of urban inequalities. Whilst traditional scientific approaches seek to increase knowledge through causality, certainty, and objectivity (de Roo 2020; Funtowicz and Ravetz 2020), complexity science acknowledges the inherent challenges in defining, solving and understanding complex problems such as urban inequality. Geographical analysis is in many ways well positioned to further our understanding of urban inequalities as it possesses a long interdisciplinary history, covers a wide range of thematic areas, and is supported by recent technological advancements and computational methods which allow for the capturing of multidimensional datasets (Franklin et al. 2022). Nevertheless, we contend that if the geographical analysis of urban inequalities is not conceived within a wider socio-technical framework that acknowledges the complex nature of urban inequalities, there are risks that it might not only perpetuate inaccuracies in representation and modeling,

but additionally support solutions or results that may not acknowledge trade-offs or underlying structural factors. Therefore, the primary question of this article is: *what perspectives and methods exist in the geospatial analysis of urban inequalities and how can we link these perspectives with ideas drawn from complexity theory to enhance our understanding of urban inequalities as a complex socio-technical phenomenon?*

Methodology

Overview

The search strategy, scope, and screening for inclusion of relevant articles is delineated in Section Search strategy, scope, and screening. This includes selecting an initial pool of articles, scanning their abstracts for eligibility, and adding additional articles through snowballing. This is followed, by a process of data extraction expanded on in Sections Data extraction and Data processing, an explanation of how we processed this data to answer the research question through developing a three-stage methodological framework, which governs the structure of this article.

Search strategy, scope, and screening

Urban inequalities are increasingly gaining traction across a wide range of scientific fields (Nijman and Wei 2020). To answer the research question requires not only the classification of research perspectives emerging from the geospatial analysis of urban inequalities, but also critical examination of their theoretical contributions. While we acknowledge that there is a wide range of literature on this topic, to enable a diverse overview, which simultaneously allows for an in-depth examination of the theoretical content of each paper, a limitation of a sample of 150 papers is applied. The initial sample of 150 papers is gleaned based on a keyword search in Scopus, employing the word "inequality" and by targeting journals specifically related to urban disciplines. This includes journals centered on transportation, such as the *Journal of Transport Geography*, urban planning, and policy, such as *Cities*, sustainable development such as *Nature Sustainability* and Geography such as the *Geographical Journal*.

While we acknowledge that there are many related terms to inequality, such as "justice" or "equity," a sufficient number of papers are found within this search term. Subsequently, each of the abstracts is reviewed to ensure that they fall within the scope of the article. In defining the scope, it is important to recognize differences between "inequality" and "equity." Concepts of equity can best be equated with "fairness" or "justice" (Van Wee and Geurs 2011:351). Indeed, not all scholars consider inequality as unfair and, in fact, fairness sometimes arises at the price of treating people differently according to their differences (Dworkin, 1981; Rawls, 1999; Sen, 2009 in Pereira, Schwanen, and Banister 2017); while the term "equality" refers to the distribution of a particular resource or phenomenon, irrespective of moral judgment. The point of our research does not lie in engaging with the underlying ethical premises that underpin a concept such as "inequality" or "equity," but rather to deduce how inequalities are being studied through geospatial analyses in the context of cities. Therefore, papers are not discarded grounded in ethical concerns of fairness or representation, but only if they are based on purely conceptual or qualitative evidence or fail to adequately consider the spatial or temporal nature of urban inequalities. A total of 32 papers are discarded and 18 papers added through backwards and forwards snowballing, leading to a grand total of 136 papers, refer to Fig. 1.

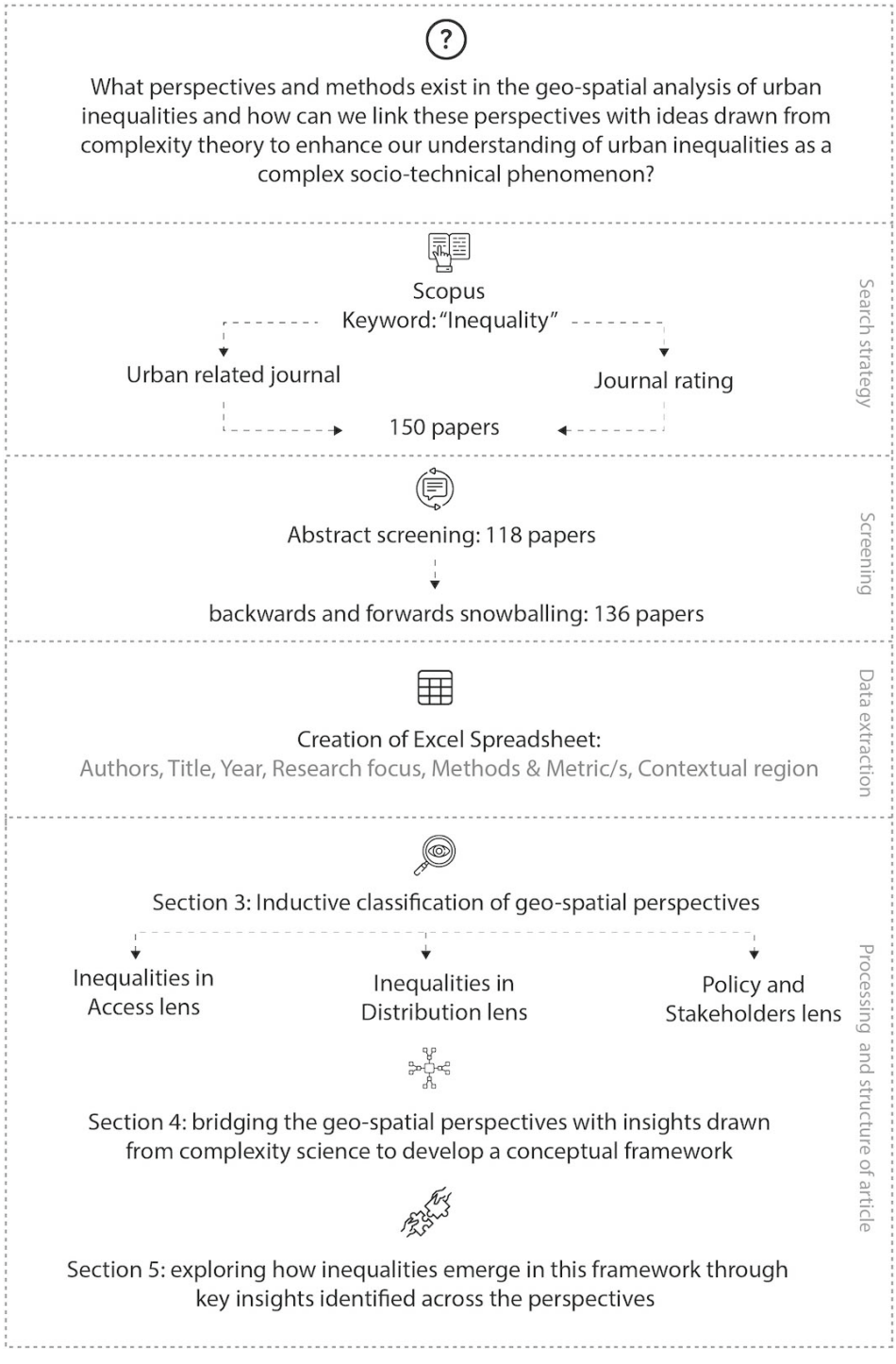

Figure 1. A visual representation of the methodological process and structure of this article.

Data extraction

Meta data from each paper is extracted and added to an Excel spreadsheet database. The spreadsheet captures the title of each paper, authors, year of publication, main research area, primary methods employed, and contextual region of focus. The majority of the papers are published after 2015, which perhaps is indicative of growing interest in the research of urban inequalities. We did not control for context and the distributions of contextual regions across the papers are as follows: 30% are focused on Europe, 21% USA and Canada, 20% on Asia, 10.5% Latin America, 5.5% Africa, 7% mixed regions, 4% the Middle East and 2% New Zealand, and Australia.

Data processing

In response to the research question, a three-stage process is developed, which governs the structure of this article, refer to Fig. 1.

The first stage involves examining the Excel spreadsheet to ascertain each paper's central research focus, methods and/or metrics. Examples of research areas are access to healthy food outlets, distribution of wage inequalities or policy experiments relating to housing wealth inequalities. Examples of metrics and methods are accessibility measures based on cumulative measurements, statistical analyses, and GIS analyses accompanied by semi-structured interviews. In examining these characteristics, similarities between the papers emerge allowing for their inductive categorization. We find three predominant research perspectives based on inequalities in accessibility, distribution, and policy and stakeholder perspectives. While these perspectives are not necessarily mutually exclusive, each perspective is generally associated with a specific research focus and families of metrics. A total of 27% of the papers adopt an 'inequalities in accessibility' perspective, 43% adopt an 'inequalities in distribution' perspective, and 30% a policy and stakeholder perspective. We discuss the geospatial perspectives in greater depth in Section Classification of perspectives on urban inequalities.

The second stage bridges the geospatial perspectives with insights drawn from complexity science in Section Consolidating the perspectives using complexity theory. While many authors within geographical analysis recognize the value in linking their work with complexity science, there is less research that has explicitly connected the geographical analysis of urban inequalities with a complex systems approach. Through reading the papers in more depth, we abstract the primary social and critical infrastructure systems in cities and propose an overarching conceptual framework of how urban inequalities emerge through their interaction over space and time.

The final stage builds on this framework and consists of inductively identifying and analyzing conceptual themes and relational trends across the literature in Section Social-technical processes that reproduce urban inequalities: A critical discussion of key relational insights. The intention of analyzing these relational trends is to enhance our understanding of the interactions between the social and technical subsystems in cities that lead to the emergence of urban inequalities over space and time.

As is the case with other systematic reviews, we acknowledge the possibility of exclusion of relevant articles. Various limitations of the methodology are reflected in the conclusion section of this paper and inform scope for future research. Nevertheless, considering the number of papers and domains covered, we are confident that our review does not suffer from significant bias and presents a comprehensive snapshot of current research into urban inequalities.

Classification of perspectives on urban inequalities

The use of data and digital technologies are at the center of contemporary geospatial analyses of urban inequalities. The practice of geospatial analysis is transforming with the advent of new digital technologies, availability of real-time data and increased computing power (Singleton and Arribas-Bel 2021). Many traditional techniques, such as surveys and hand drawn maps, are being displaced by crowdsourcing mapping such as OpenStreetmap, social media data, movement data generated through digital systems such as the Oyster card, GIS technology, and satellite remote sensing (Batty et al. 2012). This digital revolution is allowing us to develop a broader conceptualization of urban inequalities and study it across a range of dimensions, beyond traditional economic metrics. Researchers studying inequalities are embracing new forms of data such as the exploration of socio-spatial inequalities through geotagged tweets in Kentucky, USA (Shelton, Poorthuis, and Zook 2015), the use of a crowdsourcing tool in Shenzhen, China to harvest travel times to healthy food stores (Su et al. 2017) and real-time navigation route measurement to explore inequalities in access to greenspace (Chen, Yue, and La Rosa 2020).

In the context of these recent methodological advancements, it becomes important to identify not only the associated methods which are being applied to the analysis of urban inequalities, but the underlying conceptual perspectives which govern decisions to use specific methods that focus on quantifying different aspects of urban inequalities. Similarities emerge through noting the central research objectives, subject area and applied metrics and methods of each paper. This leads to the descriptive categorization of each paper into one of three predominant research perspectives. These perspectives may overlap and are not completely mutually exclusive, but in their categorization allow for comparative discussion. We believe that they contribute to a new way of thinking about the geospatial analysis of urban inequalities and highlight and recognize different research communities within the field. These perspectives are:

- Inequalities through an accessibility lens
- Inequalities through the lens of distribution
- Inequalities through a policy and stakeholder lens

Inequalities through an accessibility lens

There is a significant body of literature that is concerned with inequities and inequalities in accessibility. Accessibility has become central to planning over the last 50 years (Batty 2009:191) and is conceived in many ways such as opportunities for potential social interaction (Hansen 1959), activities that can be reached (Morris, Dumble, and Wigan 1979) and as the relation between land use zoning and transport allowing opportunities for individuals or groups to participate in different locations (Geurs and van Wee 2004). Geurs and van Wee (2004) propose that accessibility conceptually possesses clear, temporal, land use, transport, and individual components and it is the strength of the relationship between these components give rise to levels of access. Therefore, individuals, groups and regions inevitably do not have equal access to amenities (Van Wee and Geurs 2011). While, unequal access is not inherently problematic, it can be linked to negative social outcomes, such as social exclusion (Lucas 2012).

Accessibility studies concerned with urban inequalities are researched primarily on three levels. The first level is through exposing a transportation disadvantage in access associated with a certain socioeconomic group or region within a city. These kinds of studies shed light on barriers which hinder access to transportation. Examples of barriers include affordability on

the cost of mode share schemes (e.g., bicycle sharing in London; Goodman and Cheshire 2014), or a deficit in existing infrastructure that affects certain populations groups (e.g., such as the physically disabled in Melbourne; Dolgun, 2020). Distance is also identified as a potential barrier, as demonstrated by Anaya-Boig, Cebollada, and Castelló's (2022) study of the location of bike-sharing stations in Barcelona.

The second level is through uncovering disadvantages in access to specific amenities, like grocery stores (Logan et al. 2021), services, such as COVID-19 health care facilities (Pereira et al. 2021) or employment opportunities (Slovic et al. 2019). These kinds of studies emphasize specific negative socio-spatial conditions, which arise out of these weak relations such as *spatial mismatch*. The term *spatial mismatch* describes a situation that occurs when the economically disadvantaged are required to travel further to reach and access jobs (Oviedo 2021). Refer to Section Linking complexity theory with geographical analysis for a more in-depth discussion on the relation between spatial segregation and inequalities.

The third level of accessibility research is based on understanding how inequities in access may contribute to processes that enhance or decrease inequalities. For example, how particular geographies of accessibility, can intensify or attenuate pre-existing socioeconomic inequalities over time (Blanco and Apaolaza 2018). Alternatively, research may emphasize the relation between accessibility and housing prices, to shed light on the latent effects this relation has with processes of gentrification, which ultimately drive poorer residents out of centrally located zones (Smith et al. 2020). This level will often incorporate longitudinal data, in contrast to the other levels which tend to rely on cross-sectional data.

Popular methods and metrics within accessibility perspectives

The first branch of metrics of accessibility is derived from transport geography but is frequently adapted to reflect components of equity more strongly, by incorporating competition effects. For example, *Cumulative opportunities* refer to the number of amenities or services that can be reached within a given time, distance, or cost. These are often relied upon as the results are easy to calculate and communicate (Geurs and van Wee 2004). However, a well-known limitation of this indicator is that it overlooks congestion effects since it neither does account for potential population demand nor for levels of service supply (Pereira et al. 2021:2). This has led to the development of a family of methods known as *Floating Catchment Area* (FCA) Methods, which introduce competition effects to reflect supplier to demand ratios. These methods include the *Two-step FCA Method* (Luo and Wang 2003), the *Three-Step Float Catchment Area* (Wan, Zou, and Sternberg 2012), *the Modified Two-Step FCA* (Delamater 2013), and the *Balanced Float Catchment Area* (Pereira et al. 2021). The different methods are similar but weigh and calculate demand and supply slightly differently. FCA methods are generally considered better at reflecting equity components than simple cumulative measures; however, it is noted that they can overestimate both service demand and supply, potentially generating misleading accessibility estimates (Pereira et al. 2021).

The second branch of metrics encompasses the adaption of Economics indices as a measurement of accessibility. The Gini Index is one of the most widely used indices for economic inequality and can be easily understood as an increasing function of the area between a Lorenz curve and the diagonal line representing perfect equality. These metrics are being transformed to reflect distributions of access, as opposed to income, across population groups (Lucas, van Wee, and Maat 2016; Lope and Dolgun 2020; Giannotti et al. 2021). However, there are limitations, such as the fact that it can be difficult to compare different geographical contexts.

TABLE 1. Popular Metrics/Methods in Inequalities in Accessibility Research

Category	Recent examples	Topic	Metrics
Cumulative + gravity measurements	Smith et al. (2020), Anaya-Boig, Cebollada, and Castelló (2022), Luo and Zhao (2021)	Employment, Bike sharing, High-speed rail	Cumulative travel times Cumulative distance Gravity model
Accessibility indices	Martínez et al. (2018), Moreno-Monroy, Lovelace, and Ramos (2018), Cohen (2020)	Social housing, Schools, Method focused	Composite index, created an index, personal travel impact index
Adapted cumulative + gravity metrics	Giannotti et al. (2021), Pereira et al. (2021), Giannotti, Tomasiello, and Bittencourt (2022)	Transit, Healthcare, Jobs	Two-step FCA, balanced FCA, adapted gravity measure
Adapted economic metrics	Lope and Dolgun (2020), Lucas, van Wee, and Maat (2016), Logan et al. (2021)	Trams, Method focused, Amenities, Burdens	Lorenz curve, Gini index Lorenz curve, Gini index Kolm-Pollak EDE
Space syntax	Rokem and Vaughan (2019), Garnica-Monroy and Alvanides (2019), Jiang and Yang (2022)	Mobility, Activities, Green space	Space syntax network analysis

The Gini Index does not focus on absolute levels, therefore cities in theory could possess very different levels of overall accessibility, but depending on how access is distributed, similar Gini coefficients. Having said that, it can be a useful index for comparing different scenarios in the same city or region.

The final branch of methods is embedded within network analyses, such as space syntax (Hillier and Hanson 1984). These directly aim to measure the effects of the spatial configuration, through employing graph-based network analyses on the topological form of the street network. This provides measurable scales of accessibility, from segregation to integration, of each street, enabling statistical comparison of different spatial forms (Vaughan 2007). Whilst space syntax models do not directly consider the effects of activities or land use zoning, they can be weighted to reflect these components (Chen and Karimi 2017).

Popular metrics and methods employed within recent inequalities in access research are listed in Table 1. It is beyond the scope of this review to provide an in-depth account of each of these metrics, please refer to the referenced texts if that is what is required.

Inequalities through a distribution lens

Studies from an accessibility perspective predominantly focus on disparities of access to a certain resource/service by a particular group, individual or region, whereas a distribution focused perspective tends to examine how a specific phenomenon, such as housing ownership (Wang et al. 2020) or internet use (Singleton, Alexiou, and Savani 2020), is distributed across geographies of space and time. Depending on the focus of the study, a variety of multidimensional

variables and scales may be incorporated, in contrast to accessibility perspectives which are generally centered on the city scale. On the one hand, this can lead to interesting and contextually relevant insights, but on the other hand may render comparisons between research outcomes difficult.

Distribution perspectives are researched primarily on two levels:

- Cross-sectional studies of current distributions.
- Longitudinal studies mapping changing distributions over time.

Cross-sectional studies emphasize inequalities that arise out of the distribution patterns of a specific phenomenon. These could be inequalities associated with the distribution of a specific socioeconomic phenomena such as crime (Metz and Burdina 2018) or patterns of evictions (Medina et al. 2020). Alternatively, research may focus on the social outcomes of the distribution of specific infrastructures such as bus routes (Liu and Duan 2020) or educational facilities (Owens and Candipan 2019). Another line of inquiry is centered on inequalities relating to the environmental quality of different regions, such as pollution levels (Ruttenauer 2019). These studies provide useful insights into distribution patterns within a particular region, but it becomes difficult to draw general conclusions as they are very contextually focused and tend not to adhere to a common framework which makes them easily comparable.

Longitudinal studies, in contrast, shed light on the emergence of processes of distribution, which create or enhance geographical inequalities over time. Such processes could be related to globalization (Boschken 2022), the housing market and economy (Musterd et al. 2017) or urban development (Modai-Snir and van Ham 2018). These kinds of studies also emphasize, importantly, that factors driving socio-spatial processes can operate on varying spatial and temporal scales. For example, labor market dynamics are strongly affected by global influences, while welfare systems are mainly set on national levels, housing prices vary between and within cities and the study of neighborhood effects is primarily conducted at the scale of the neighborhood (Nieuwenhuis et al. 2020), refer to Fig. 2. In fact, the study of neighborhood effects is a well-defined body of the literature on its own. Examples include Chen, Myles, and Picot (2012) who show stagnation in income increases in lower income neighborhoods in Canadian cities, leading to increases in inter-neighborhood inequalities between wealthier and poorer neighborhoods and Patias, Rowe, and Arribas-Bel (2021) who unveil varying pathways of socioeconomic change in Britain highlighting neighborhoods of persistent disadvantage and inequalities over a 40-year period. In summary, the advantage of adopting a longitudinal and process focused approach, is that identified processes tend to be more generic, such as the process of gentrification for example, thus increasing comparability across contexts.

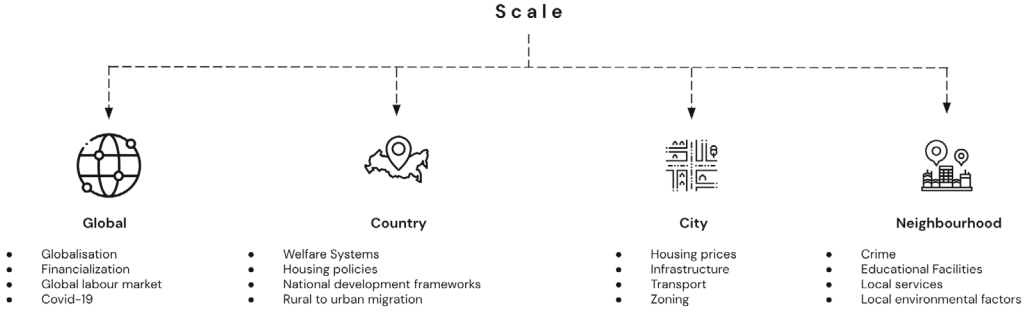

Figure 2. A representation of the multi-scalar nature of different socio-spatial processes.

The contributions of geographical information systems (GIS) in understanding the various facets of these longitudinal, multi-scalar and multi-dimensional processes are diverse. As Delmelle, 2022:2 states "GIS is instrumental in the creation of spatial variables used in longitudinal statistical models to tease out causal mechanisms and key explanatory variables behind changes." Evidence of patterns within these conditions can support decision-making by identifying where action is urgent and which policies and interventions are needed to enhance positive impacts while mitigating negative impacts.

Popular methods and metrics within distribution perspectives

Multiple variables and dimensions may be considered when studying inequalities in distribution patterns. Thus, data-reducing techniques are commonly employed to group variables to reduce their complexity, but also, importantly, retain relevant information (Arribas-Bel 2019). This in theory results in easier-to-understand outputs, in which relations between the variables are emphasized. Common data-reducing techniques include:

- Principal component analysis (PCA) is a technique for reducing the dimensionality of data sets, increasing interpretability, whilst concurrently minimizing information loss, as an example refers to Dong (2018).
- Clustering techniques find categories or groups of observations that are similar, based on a combination of variables to reveal relationships between variables. Typically, unsupervised machine learning techniques such as k-means clustering are employed, for example refer to Wind and Hedman (2018).
- Recently sequence analysis is applied to neighborhood trajectories which unveil varying pathways of inequalities, for example, refer to Patias, Rowe, and Arribas-Bel (2021). Sequencing methods originate from genealogy science but are adapted particularly to reduce the trajectory of neighborhoods to a set of discrete events to classify sequences of change (Delmelle 2022). Neighborhoods belonging to similar sequence groups can then be further classified into similar trajectories.

To compare the effect of different spatial configurations, researchers have developed methods to formally include space into statistical models. The inclusion of spatially lagged variables has arisen out of the need to represent space formally, in essence translating geography into numbers (Arribas-Bel 2019). When studying distributions related to inequalities this can be important, as may account to what extent inequalities mac be affected by its spatial location and where it has been zoned in the city. Formally, spatially lagged variables are statistical variables which are weighted based on their spatial location to account for the characteristics of proximal "neighboring" spatial units and their spatial effects. The way in which, a "neighbor" is defined depends on the researcher, it can be based on the positioning of neighboring spatial units, a distance parameter or alternatively on something loosely related to geography such as the sharing of postcodes. Limitations of these methods pertain to the fact that different spatial models can create distinctly different spatial correlation patterns (Anselin 2002). Therefore, a relatively deep understanding of how spatial weights should be constructed is required for capturing the theorized spatial interaction.

The predominant methods or metrics employed from this perspective are briefly summarized in Table 2, if an in-depth account of each of these metrics is required, please refer to the referenced texts.

TABLE 2. Popular Metrics/Methods in Inequalities in Distribution Perspectives

Category	Recent examples	Topic	Metric
Spatial auto-correlation	Metz and Burdina (2018)	Crime	Cliff-Ord model
	Medina et al. (2020)	Evictions	Moran's I
	Li, Wei, and Swerts (2020)	City-regions	LISA
Composite indices/matrices	Chen, Myles, and Picot (2012)	Neighbourhoods, socio-spatial mobility	Gini coefficients, deprivation matrix, index of dissimilarity
	Nieuwenhuis et al. (2020)		
	Lloyd et al. (2021)		
Data reducing techniques	Dong (2018)	Rental affordability, digital inequalities, neighborhoods	PCA clustering, sequencing
	Singleton, Alexiou, and Savani (2020), Patias, Rowe, and Arribas-Bel (2021)		
Statistics/machine learning	Whitworth (2013)	Crime	Spatial regression
	Dorling (2010)	Population	Descriptive statistics
	Molar-Cruz et al. (2022)	Urban growth	Random Forest

Policy and stakeholder perspectives

The two previous perspectives often highlight the importance of their results for policy but are not explicitly centered on specific policies or stakeholders. This perspective is characterized by an intentional focus on policies embedded within particular institutional contexts and distinct time periods. Research from this perspective frequently integrates quantitative insights drawn from geographical analysis with participatory processes. Researchers might explicitly adopt a critical GIS approach, which actively seeks to challenge the representation of geographies and their relations with policy and power. Alternatively, they might test assumptions to expose urban inequalities within, as a result of or potential outcome of policy and decision-making processes. Research in this area is broadly categorized into:

- The effects of historical policy on contemporary development.
- The effects of contemporary policy and governance measures in relation to specific stakeholders.
- Potential policy scenarios and their impacts.

Analysis of historical policy seeks to link current socio-spatial conditions with policies implemented in the past. An example of such an investigation is by Faber (2021) into how the practice of redlining in the USA in the first half of the 20th Century funneled billions of dollars of mortgage credit away from Black neighborhoods. See Section 5.2 for a more comprehensive discussion on the practice of redlining. Faber (2021) argues that this practice shaped contemporary segregation patterns and home ownership inequalities. Li, Wei, and Swerts (2020) also adopt a historically focused approach, suggesting that China's economic policies of capital and labor-intensive growth have led to high productivity clusters centered on

mega-cities causing rising inequalities between city regions. Historical policy analysis highlights how present urban inequalities arise out of past decision-making processes, shedding light on path dependencies.

In contrast, Rodríguez-Pose and Storper (2020) scrutinize contemporary thinking around policy that promotes housing construction in prosperous areas to increase supply as a route to greater equality in cities within the USA. They argue that policy aimed at the reduction of income inequalities should rather focus on the geography of employment, wages, and skills. An analysis of inequalities within the distribution of a water supply network across the city of Lilongwe, Mali is linked to insights gained through an ethnographic study of government workers (Alda-Vidal, Kooy, and Rusca 2018). Direct engagement with municipal workers reveals that they believe lower income residents can cope better with less water, therefore they prioritize the delivery of water to higher income areas when shortages occur. Studies which focus on contemporary policy, tend to highlight current geographical inequalities that might affect specific stakeholders or geographical regions.

Several studies explore, or critique proposed infrastructure and policy scenarios. These may be existing design proposals or future urban policy scenarios. The proposal of a six-mile biking and walking path around downtown Portland is critiqued by Mahmoudi, Lubitow, and Christensen (2020) building on critical GIS insights. They combine digitized spatial data from participatory mapping exercises with lower-income residents who reside in outer Portland neighborhoods. This reveals that wealthier, White, centrally located residents will have much higher rates of access to the proposed project, thus suggesting that this proposal could reinforce unequal development patterns and challenging the equity rationale of downtown investment. While, Tomasiello, Giannotti, and Feitosa (2020), conduct a series of experiments that simulate policy and design scenarios in Sao Paulo regarding the implementation of social housing and transport, deriving policy recommendations based on the optimal results. Along this line of thinking, Guerrero (2020) presents a study containing a series of computational experiments of policies to reduce housing wealth inequalities through the calibration of a one-to-one scale model of 25 million U.K. households to estimate market effects. Studies with a future policy focus may either address a multitude of potential future scenarios, exploring the outcomes of different ones or provide counter evidence to challenge a specific future scenario.

Popular methods and metrics within policy and stakeholder perspectives

There are two predominant methodological approaches employed within this research perspective. The first approach involves the integration of geographical analysis with evidence gleaned from participatory processes. For example, as previously discussed, Alda-Vidal, Kooy, and Rusca (2018) link an analysis of the water supply network in Lilongwe, Mali with an ethnographic study involving government workers to expose underlying assumptions which lead to emergent inequalities. While this kind of research tends to be more descriptive in nature, its value lies in the teasing out of underlying, experiential factors which one would be unlikely to capture through geographical representation alone. It is also important to recognize that if this research does not represent all the stakeholders' views equally and objectively, it could potentially reinforce a potentially biased argument.

The second approach is embedded in providing evidence which attempts to assess the outcomes of past, present, or future policy through advanced statistical or computational analysis. For example, Guo, Buchmann, and Schwarz (2019) simulate urban development patterns using an agent-based model (ABM), to understand if policy is needed to regulate the relationship between

TABLE 3. Popular Metrics/Methods from Policy and Stakeholder Perspectives

Category	Recent examples	Topic	Metric
Interviews and/or surveys	Cooper and Vanoutrive (2022), Lin and Polsky (2016), Guo, Zhu, and Liu (2018)	Ethical frameworks Vulnerability, Typhoons, Urbanization	Semi-structured Interviews + surveys, Surveys
Stakeholder engagement/ethnographic	Tseng and Penning-Rowsell (2012)	Flood risks	Stakeholder engagement
	Mahmoudi, Lubitow, and Christensen (2020)	Urban mobility	Participatory
	Alda-Vidal, Kooy, and Rusca (2018)	Water Governance	Ethnographic
GIS statistics	Faber (2021)	Redlining	Digitization
	Roy et al. (2018)	Spatial segregation	Regression
	Marsh, Parnell, and Joyner (2010)	Racial inequalities	GIS
Agent-based modeling (ABM)	Tomasiello, Giannotti, and Feitosa (2020)	Social housing	ABM
	Guerrero (2020)	Tax + Housing	ABM
	Guo, Buchmann, and Schwarz (2019)	Urban sprawl	ABM

urban sprawl and income segregation. ABMs are developed specifically to simulate outcomes as complex processes emerging out of individual decisions and actions (Jackson, Forest, and Sengupta 2008; Liu and O'Sullivan 2016). These models can evaluate how certain conditions result in empirically observed situations and they may reveal complex or nonlinear effects that result from the collective behavior of individuals. ABMs describe how agents interact and their parameters for processing information and making choices (Blume 2015). They are particularly useful for demonstrating potential policy outcomes; testing underlying assumptions and alerting us to emergent consequences of policies centered on things like land use zoning.

The predominant methods or metrics used within this perspective are summarized in Table 3.

Challenges and limitations of the perspectives

It is important to develop a critical understanding of data and their role in the geospatial analysis of urban inequalities across the perspectives. The use of data has limitations relating to privacy concerns (Batty et al., 2012:515), inequalities in availability across different regions (Franklin et al. 2022) and issues of equal and equitable representation (Basiri and Brunsdon 2022). Datasets can be biased depending on the way that data is collected, such as, for example, large rural areas in the Global South remaining unmapped in the popular volunteered geographical information platform OpenStreetMap (Li et al. 2022), which may mistakenly suggest that little exists there.

While, the geospatial analysis of data may be presented as objective and neutral, it does not exist in a vacuum from the ideas, instruments, practices, knowledges, and systems used to process and analyze them (Lauriault 2012; Ribes and Jackson, 2013 in Kitchin et al., 2015:16). There

are ethical consequences (Kitchin et al., 2015:16), especially in the analysis and interpretation of urban inequalities. The interpretation of results is imperative in understanding systemic factors behind observed patterns and trends and involves a process of cognition that requires drawing on external, contextual knowledge (Kandt and Batty, 2021:7). If researchers rely on outdated normative theories that fail to consider the needs of diverse populations, they are at risk of reinforcing inequalities (Franklin et al. 2022). These concerns speak to the heart of geospatial analysis, as it is ultimately a process of representation and researchers need to be mindful that in representing and interpreting urban inequalities, they may also be reproducing biases.

Linking the interpretation of results to a broader systems framework that acknowledges the inherent complexity of urban inequalities is an important consideration that is often overlooked across the perspectives. We propose that if the geospatial perspectives are not explicitly linked to a complex systems framework, we are at risk of not only representing, modelling, and interpreting urban inequalities inaccurately, but also supporting solutions that do not acknowledge inherent trade-offs or the underlying causal factors which reproduce them. The subsequent section of this article thus develops a socio-technical framework for urban inequalities through linking the perspectives to ideas drawn from complexity theory.

Consolidating the perspectives using complexity theory

In this section we argue for the increased integration of perspectives within the geographical analysis of urban inequalities with insights drawn from complexity science, which has seen a recent revival in urban planning and responds to the call from UN-Habitat (2016) for applied systems approaches to better understand urban environments (Patorniti et al., 2018:281). We contextualize complexity science in relation to geographical analysis, followed by the proposal of a socio-technical framework for examining how inequalities are reproduced in urban systems.

Linking complexity theory with geographical analysis

Complexity science, originating in physics and mathematics, is being applied to many different disciplines. Complexity theory can be understood broadly as a way of thinking, understanding, and approaching problem solving (Zellner and Campbell 2020). As a scientific paradigm it classifies problems based on their level of complexity and recognizes specific characteristics of complex problems (Calenbuhr 2020). Broadly, a complex systems framework acknowledges that complex problems are embedded within complex systems. There are many different definitions of complex systems (Messina et al. 2008), but generally a complex system is understood as a relational system composed of the interactions between complex processes. A complex systems framework recognizes that complex systems by their very nature are difficult to describe (De Roo, 2020:2), reinforced by feedback dynamics between relational components, that are not linear in cause and effect (Alexander, 2020:19) and can produce new, emergent patterns of self-organization (Portugali 2000).

Geographical analysis covers a diverse set of methods, tools, thematic areas, and theories. Importantly geographical analysis is centered on the generation of a diverse body of knowledge associated with the unique characteristics of spatialized data (Singleton and Arribas-Bel 2021). A number of researchers within geographical analysis recognize the value in engaging with ideas and methods drawn from complexity science, such as ABM (Crooks et al. 2019). The application of complexity science to the study of cities is not novel. Hillier (1999) defines cities as strongly relational systems, as systems in which the relations of each element to all other elements are

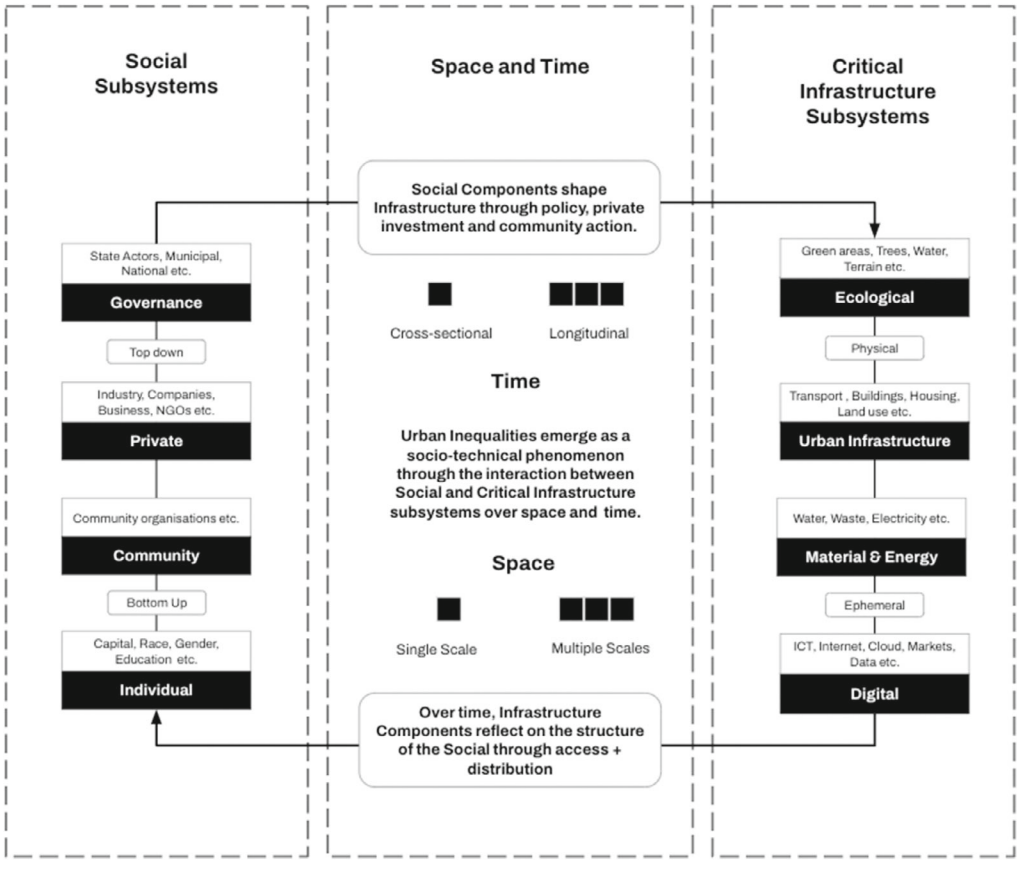

Figure 3. A conceptual model of the urban as a complex socio-technical system, framing urban inequalities as an emergent socio-technical phenomenon that develops over space and time.

more important for the functioning of the system than the intrinsic properties of the elements themselves. Batty (2013) in his book, *The New Science of Cities*, advances this thinking by characterizing the city as a system composed of many subsystems that does not exist in a benign environment, but is dynamic, being less defined by individual locations and more by flows of relational networks.

Applying systems thinking to the geospatial perspectives identified in the previous section of this review, reveals that they broadly focus on the *interaction* between different aspects of social dynamics in cities (e.g., individual characteristics of specific demographic groups or government entities) and critical infrastructure (e.g., public transportation or clean water). The emphasis is on the *relation* between these components, as opposed to the characteristics of a single component. To engage with the complex system which reproduces inequalities, we abstract the different *Social*, *Spatial*, *Temporal*, and *Critical Infrastructure* subsystems that exist within cities and illustrate the primary mechanism which reproduces urban inequalities, represented in Fig. 3. Decisions on the development and management of critical infrastructure originate from the *social subsystem* through governance and policies, the private sector and community action. However, the *critical infrastructure system* reflects back into the structure of the Social subsystems through access and distribution. In this way, urban inequalities emerge as a complex socio-technical phenomenon.

In unpacking the interactions between the components of each system, it is important to realize that they interact within different relational hierarchies. The *Governance networks* are positioned at the top of the *Social*, reflecting their "top-down" influence. Through centralized policy and legislation various levels of government, regulate different aspects of urban life. In contrast to *Governance networks*, the *Individual component* is located at the lower end, echoing their "bottom-up" effects. Unlike *Governance networks*, this component may not possess an apparent order, but that does not mean it lacks structure. Out of individual behavior and actions, emerging patterns can arise, such as, for example, the study of informal minibus taxis by Nelson (2021) that shows despite being an informal system, it has an emergent structure of behavior. Community and private organizations, are placed in-between, as play a negotiating role between *Governance networks* and the *Individual*. The *Digital systems* are positioned at the lower end of the *Infrastructure Components*, as despite being pervasive, are generally invisible to the naked eye. *Material and Energy flows*, such as sewage systems and electric cables, also tend to be hidden from view and used intermittently. In contrast, *Ecological Infrastructure*, such as rivers and parks, and *Urban Infrastructure*, where systemic inequalities are prevalent in the distribution of amenities (Nicoletti, Sirenko, and Verma 2022) have direct, material interfaces with the social world.

The way that *Critical Infrastructure* and *Social Components* interact is mediated through different spatial and temporal scales. Bettencourt (2013) reveals that as the size of a city grows and the density of its population and infrastructure increases, the rate and intensity of these interactions also increases. Urbanization is an ongoing and dynamic process (Bulkeley and Broto 2012). Space through its very form and configuration can express social potentials and carry social contents, and thus can take part in the active production and reproduction of society and in this way plays a constructive as well as receptive role in shaping the forms of social action we see in cities (Hillier and Netto 2002:182). Hillier and Hanson (1984) in *The Social Logic of Space*, argue that space–time is a medium through which cultural and socio-economic patterns are reproduced in society. To illustrate this point, the political system of Apartheid, in South Africa implemented a spatial system of segregated neighborhoods delineated by race. Although this political system officially ended in 1994, the spatial system endures and continues to affect contemporary demographic residential patterns, which remain highly racially segregated by these enforced racial classification patterns (Nelson 2021).

The research perspectives identified in Section Classification of perspectives on urban inequalities, usually focus on the interaction between two or more of the subsystems represented in Fig. 3. *Governance networks* are often touched on but are usually only central to *policy and stakeholder perspectives* which tend to focus on the interaction between Government structures and a specific socioeconomic group; while *accessibility perspectives* generally concentrate on the interaction between *Urban Infrastructure* in relation to characteristics of the *Individual* or *Community*, such as the relation between certain population groups and employment opportunities. *Distribution perspectives* also focus on this, but more frequently incorporate *Networked Material and Energy flows* and *Digital Components*, such as Singleton, Alexiou, and Savani's (2020) analysis of internet use in Britain. In this way, urban inequalities can be thought of as a phenomenon resulting from the interactions between the varying components, across geographies of space and time, depicted in Fig. 3.

Social-technical processes that reproduce urban inequalities: A critical discussion of key relational insights

As Batty (2013:39) advocates, "To understand place, we must understand flows. To understand flows, we must understand networks. Networks suggest *relations* between people and places." To deepen our understanding of the relations between the social and technical processes that lead to the reproduction of urban inequalities through space and time, the subsequent section presents a critical discussion on key relational themes and trends identified across the geospatial research perspectives.

- The relation between heightened spatial segregation and increasing inequalities.
- The relation between individual outcomes and neighborhood dynamics.
- The relation between widening income inequalities and the decreasing redistributive power of the State.
- Intersections between inequalities and identity in space.

The relation between heightened segregation and increasing inequalities

Heightened spatial or digital segregation can represent a weakness or disconnect in the relationship between aspects of the social and critical infrastructure subsystems across space and time. From a measurement perspective, inequality and segregation are two closely related concepts. While inequality refers to the distribution of an individual property, such as income within a population, segregation refers to the distribution of the individuals in a population, in relation to a specific property, such as income (Scarpa 2015). Inequalities are not necessarily always associated with high levels of spatial segregation, but when heightened levels of spatial segregation occur alongside high levels of inequality, they are at risk of forming a vicious, reinforcing cycle (Nieuwenhuis et al. 2020). The relations between inequalities and segregation are generally conceptually understood and interpreted in primarily three ways:

- The effects of rising inequalities on segregation.
- The effects of segregation on inequalities.
- The effects of processes which reinforce the relation between inequalities and segregation.

In relation to the effects of rising income inequality on segregation, Reardon and Bischoff (2011) provide evidence of a positive association between these phenomena in U.S. metropolitan areas. They argue that increasing differences in purchasing power ultimately determine the housing pools people can access, which is resulting in increasing polarization of households in separate residential areas. Similarly, Chen, Myles, and Picot (2012) suggest that in recent decades, the increase in economic residential segregation in Canadian metropolitan areas is primarily caused by rising income inequalities. Scarpa (2016) through longitudinal analysis shows that in Sweden, in the period between 1991 and 2010, rising income inequalities contributed to the development of residential segregation by income. While Cheshire (2012) advocates that residential segregation can be understood as the spatial manifestation of wider economic and social processes that create inequalities in society and lead to the sorting of concentrations of different kinds of earners into separate neighborhoods.

Conversely, in thinking about the effects of economic residential segregation in reinforcing income inequalities, the classic study of Wilson (1987), suggests that living in economically deprived neighborhoods enhances deprivation. Slovic et al. (2019) illustrate how vulnerable populations in Sao Paulo experience spatial mismatch through being required to travel and pay

more to reach employment. Martínez et al. (2018) highlight a similar condition in Santiago, Chile, emphasizing that social housing zoning policies have served to reinforce spatial mismatch through being placed in peripheral locations far from employment opportunities. While Singleton, Alexiou, and Savani (2020), demonstrate that segregation also manifests digitally, showing that those who are least engaged with the internet in the UK congruently reside within the most deprived neighborhoods. Therefore, digital, and physical segregation might also contribute to widening inequalities.

The two previous paragraphs suggest that it is difficult to pinpoint causality between heightened segregation and inequalities, as contrasting studies tend to emphasize the causal role of both these phenomena. However, there is also evidence that certain urban processes may act as motors in congruently driving both segregation and social inequalities. Market based processes are shown to have an impact, for example, Smith et al. (2020) emphasize how changing housing market conditions are fueling processes of gentrification in London, driving lower income population groups out of centrally located areas and increasing their travel costs. Institutional processes are also emphasized as playing a role, such as the Hukou system in China which institutes different housing rights for migrants and local population and is identified as a major source of institutional inequalities between locals and migrants (Huang and Jiang 2009; Chan 2010). The interactions between spatial segregation and inequalities are complex and third forces outside of both phenomena may reinforce the cyclical nature of their relationship.

Social and cultural patterns embed themselves in spatial layouts and there are always degrees of segregation (Vaughan 2007). Causality between inequalities and segregation is difficult to empirically prove, but there is evidence that suggests that specific combinations of socio-economic, spatial and/or digital vulnerabilities can lead to conditions of both increasing spatial and economic polarization through disconnection between aspects of the social and critical infrastructure subsystems (Martínez et al. 2018; Slovic et al. 2019; Singleton, Alexiou, and Savani 2020).

The relationship between individual outcomes and neighborhood dynamics

The relation between individual outcomes and neighborhood dynamics interplay through the spatial proximity of communal sharing of social and critical infrastructural resources over time. The effects of structural and social differences between neighborhoods on individual outcomes has been an area of interest since Wilson (1987) study on concentrated poverty in African American ghettos in the USA. A wide range of theoretical developments followed, with evidence supporting, on the one hand, that individuals influence and shape neighborhood environments, but on the other hand, that the socio-spatial characteristics of neighborhoods, can also shape individual life path courses.

Manley, van Ham, and Doherty (2011) suggest that individuals do not locate themselves randomly across neighborhoods but make residential choices in relation to their available opportunities and constraints. If residential choices reflect certain individual characteristics, such as the purchasing power and the position in society of those who make them, the possibility of moving from less advantaged to more desirable neighborhoods is then subject to the same structural constraints as other forms of upward social mobility (Scarpa 2015). There is a level of choice in where a person decides to reside, but, indeed, high-income households typically choose to live in attractive neighborhoods that are beyond the reach of low-income households (Cheshire 2012). Therefore, financial limitations have an impact on the selection of neighborhoods available to the individual.

There is increasing evidence that the communal sharing of localized opportunities, embedded within neighbourhood characteristics, impacts the collective social lives of neighbourhood residents (Sampson 2019). Historical examples of path dependency illustrate this point well, such as the institutional practice of redlining, which funnelled billions of U.S. dollars away from minority neighbourhoods in the USA, previously touched on in Section 3.5. Most Black neighbourhoods were redlined, and the financial implications of this zoning practice were severe, as most loan companies and insurers would refuse to lend money in redlined areas (Vaughan 2018:156). Faber (2021) presents evidence that suggests redlining has created contemporary structural patterns of disinvestment within historically Black neighbourhoods. Another consistent finding is the association between neighbourhood socioeconomic composition and educational outcomes (for a review, see Nieuwenhuis and Hooimeijer 2016). Kuyvenhoven and Boterman (2021) provide evidence that a neighbourhood of socioeconomic advantage in Amsterdam positively affects the advised educational level for all children of all social groups who reside in that neighbourhood, but especially for children of lower and intermediate-educated parents. A factor which is often overlooked by scholars studying neighbourhood effects is the physical composition of the neighbourhood (Sampson 2019). Sampson and Winter (2016) find, by drawing on comprehensive data from over one million blood tests administered to Chicago children from 1995 to 2013, that individuals from predominantly Black and Hispanic neighbourhoods exhibit extraordinarily high rates of lead toxicity, suggesting that the very services and infrastructure within these neighbourhoods, poisoned their residents. As these studies note, certain behaviour is not produced by a certain neighbourhood, however, they do illustrate that social, spatial, and physical characteristics of neighbourhoods can affect the collective well-being of neighbourhood residents.

Whilst individuals to a certain degree decide which neighborhoods they reside in, their purchasing power can seriously limit these decisions (Manley, van Ham, and Doherty 2011). Neighborhood effects are inherently contextually dependent as they relate to specific social, institutional, and spatial characteristics of a specific neighborhood. As the studies discussed in this section note, a certain behavior is not produced by a certain neighborhood, but there are impacts and increasing longitudinal studies show evidence of inter-generational impacts that can compound income inequalities over time (Delmelle 2016). This reinforces ideas around feedback loops, and the relational and dynamic nature of interaction between social and critical infrastructure subsystems as depicted in Fig. 3.

The relationship between rising inequalities and the redistributive power of the state

Governance structures and regulation (or lack thereof) influence the way critical infrastructure is distributed across space and therefore ultimately who has access to it. Income and wealth inequalities have been on the rise in almost every country since the 1980s, following a series of deregulation and liberalization programs (World Inequalities Report 2022). The World Inequalities Report (2022:15) states "Over the past 40 years, countries have become significantly richer, but their governments have become significantly poorer. The share of wealth held by public actors is close to zero or negative in rich countries, meaning that the totality of wealth is in private hands." The Report continues to show that in the UK and the USA, national wealth consists almost entirely of private wealth. The disappearance of public wealth in national wealth represents a significant change from the situation that existed in the 1970s, when net public wealth was typically between 40% and 100% of national income in most developed countries.

One sector that is receiving increasing attention, due to rising levels of wealth concentration, is real estate (Harvey 2005). Piketty (2014) analysis reveals the outsized share of property wealth in increasingly divided capital accumulation, leading to rising housing wealth concentration. Arundel and Ronald (2021) confirm these findings showing that there is declining access in home ownership in the USA, Australia, and UK, despite these countries being traditionally perceived as societies of high home ownership. Moreover Dong (2018) illustrates the relation between rising inequalities and rental affordability in metropolitan areas of the USA. Thus, not only is housing ownership decreasing in the USA, but rents are becoming increasingly unaffordable.

Compounding these problems, opportunities to build affordable housing in desirable urban areas are often passed up to expensive luxury housing (Medina et al. 2020). Van Zandt and Mhatre (2009) reveal how low-cost housing in Dallas sponsored by the State is concentrated in poverty-stricken areas, thus reinforcing polarization between wealthy and disadvantaged neighbourhoods. A similar pattern is shown in the UK, with council housing in central locations being privately sold off, evicting low-income earners, and effectively zoning them out of well-located areas (Hudson 2013). Medina et al. (2020) reveal a rising number of evictions in the USA, showing how a lack of affordable housing options leads to increasing housing insecurity. Conversely in the global South, considering a complex colonial history under which few social housing programs existed, social housing has predominantly been in the form of subsidized housing. Many of these subsidized homes are located and have been zoned to cheap land in peripheral zones, such as the case with many of the RDP homes in South Africa (State of the South African Cities Report 2016) and the Infonavit scheme in Mexico (Aguilera 2016), which creates an environment prime for economic polarization.

Whitworth (2022) argues neoliberalism has gone hand in hand with processes of Globalization leading to blanket policies that emphasize the free market, privatization, and deregulation which in turn has diminished the redistributive power of the State. This is especially problematic in lower income countries which recently gained their Colonial Independence but is also affecting upper income countries like the USA and UK (World Inequalities Report 2022). The importance of local context to national policy design and outcomes in many countries seems to have been neglected, which raises serious concerns around the continuing international popularity of neoliberal public policymaking for spatial justice (Whitworth 2022).

The intersection of identity and inequalities in space

Identity can be thought of as the qualities, beliefs, personality traits, appearance or expressions that characterize a specific group, which may be rooted in their gender, religion, race, nationality, or age. These characteristics tend to be most strongly related with the *Individual Subsystem*, as depicted in Fig. 3, and yet it is proposed that it is rather the relationship between this subsystem and other subsystems which generally have an impact on the emergence of structural inequalities. The World Social Report (United Nations 2020) underscores how characteristics related to identity such as gender and race, continue to shape opportunities for individuals. As an example, women's global share of total incomes from work (labor income) which neared 30% in 1990, now stand still at less than 35% today (World Inequalities Report, 2022:16).

In trying to unpack the relationship between identity, socio-spatial culture and inequalities, it is useful to draw on different theoretical approaches. Within Space Syntax (Hillier and Hanson 1984) spatial configurations are advocated as having a relationship with the way in which human interactions between different groups are generated and controlled, in this way spatial boundaries can serve to reinforce social differences (Hillier and Hanson 1984). In social

network theory, the concept of homophily is based on the principle that contact between similar people occurs at a higher rate than among dissimilar people (Easley and Kleinberg 2010). Therefore, whilst frequent contact between similar types of people may be thought of as a natural occurrence, there is evidence that group identities can also be reinforced through the spatial ordering of cities. A recent study by Tóth et al. (2021) demonstrates this through showing that online social network fragmentation is significantly higher in towns in which residential neighborhoods are divided by physical barriers such as rivers and railroads, suggesting a direct correlation between social network divisions and morphological characteristics of space. A different kind of study by Roy et al. (2018) concentrated on a slum in Bangalore shows how there are clear spatial agglomerations by religion, and that group identity by religion in fact plays a large role in the sharing of job opportunities. While Bagchi-Sen et al. (2020) illustrate, through a large-scale demographic analysis, that shrinking cities in the USA tend to be congruently less white, and more susceptible to financial vulnerabilities. The concept of homophily suggests that agglomeration of communities by identity might be a natural occurrence, however, research suggests it may also impact a community's ability to access social opportunities.

Policy can also play a role in reinforcing specific spatial boundaries, effecting people differently based on characteristics of their identity. The explicit spatial marking of places by institutional actors may have substantial consequences. Research into contemporary practices present evidence of cases in the USA where minority neighborhoods are excluded from incorporation into municipal boundaries, resulting in political and material disadvantages (Marsh, Parnell, and Joyner 2010). Marsh et al., (2010:691) state "They (the neighbourhoods) are part of the same employment, commuting, and retail structure. In some cases, they are surrounded by the municipality, but politically they remain on the outside looking in." Zhang, He, and Zhao (2018) show how lower income migrants in Beijing, China often do not have the right papers such as job contracts, temporary residence permits and social insurance and as a result their children do not have the right to enroll in schools, meaning that many migrant children are left in rural areas without adequate schooling. This is a case, where migrant status, especially for lower income migrants, has an impact on migrant children. When policy institutionalizes different rights based on identity, this can lead to the systematic disadvantage of specific groups.

The World Social Report (United Nations 2020) underscores how characteristics related to identity such as gender and race, continue to shape opportunities for individuals. In thinking about identity from an explicitly urban perspective, the grouping of different identities in space could be theorized to occur, to a certain degree naturally, if one accepts principles of homophily. However, the evidence suggests that if these groupings are reinforced through strong spatial boundaries and/or policy mechanisms to create systems of correspondence, this could play a factor in perpetuating systemic inequalities (Roy et al. 2018; Zhang, He, and Zhao 2018).

Discussion and research agenda

In summary, this article makes three primary contributions:

- Firstly, a multidisciplinary classification of contemporary geospatial analysis of urban inequalities leading to the identification of three predominant viewpoints: *accessibility*, *distribution*, and *policy and stakeholder perspectives*. This provides a new way of looking at the field.

- Secondly, the geospatial perspectives are related to complexity theory, leading to the development of a conceptual framework for understanding urban inequalities as a complex socio-technical phenomenon, as depicted in Fig. 3.
- Finally, the interactions between social and critical infrastructure which are related to emerging inequalities are explored through a critical discussion of key, relational themes identified across the literature. These discussions reveal divergent viewpoints which emphasize that socio-spatial perspectives are not "soft-social" issues, but intrinsic for grasping the deeper structural and institutional drivers that reproduce urban inequalities over time and space.

In attempting to position these findings, we find the following points to be key considerations for future research:

From economic to multidimensional and systemic

Most of the discourse on inequalities, until recently, has focused on economic inequalities, particularly income inequality thus advancing our knowledge of income inequality significantly (Yap, Cocina, and Levy 2021). Whilst the geospatial analysis of inequalities has expanded our understanding beyond the confines of economics, specific sets of singular indicators across separate dimensions are often focused on. Systemic and multidimensional thinking needs to be placed at the heart of the debate.

A shift in emphasis from the static and causal to the relational and dynamic

The literature regularly emphasizes causality, with urban inequalities being attested to poor distribution and access to critical infrastructure or as an outcome of the societal actions of specific groups. While, the conceptual model as proposed in Fig. 3, highlights how the two dynamically interplay through space and time. Social forces express themselves through space, but space through its very form and configuration can carry social contents, and thus take part in the production and reproduction of society (Hillier and Netto 2002:5). The complexity of interactions, interdependencies, and emergent properties within a city increase as its scale increases (Bettencourt 2013). Feedbacks and nonlinearities between its components lead to uncertainties as it dynamically changes (Batty 2013). Therefore, time and scale become key considerations, invoking important questions around the spatial (street, neighborhood, city), and temporal (tactical, long term or phased) scales of interventions or policies that attempt to address urban inequalities.

Urban inequalities are a complex socio-technical phenomenon

Cities are complex, dynamic, and highly integrated systems, which creates deep challenges for good governance, policymaking, and planning (McPhearson et al. 2016:566). This complexity has historically made it difficult for decision-makers to develop and guide development trajectories. The use of socio-technical systems approaches has been successfully applied in other domains to understand complexity (Patorniti, Stevens, and Salmon 2018:282). Understanding complex urban systems requires insight into the formation and relations between its array of subsystems. Conceptualizing urban inequalities as a complex socio-technical phenomenon allows for an engagement with the socio-technical processes which reproduce them over geographies of space and time.

Methodological development is required

New ways of integrating the identified perspectives and moving beyond unidimensional indices like the Gini Index, are essential to broaden our understanding of urban inequalities. Complex systems research has rapidly advanced, but urban planning and design disciplines are still wrestling with the use of methods informed by complexity science to capture and understand feedback, interdependencies, and nonlinearities which create uncertainties (Walloth, Gurr, and Schmidt 2014). Attempts need to be made to move away from normative theories of urban development which disregard the diverse needs and behavior of different populations. The modelling of complex systems allows for opportunities to include and represent the dynamic experiences and diverse characteristics of populations and contexts to support decision making. This raises interdisciplinary challenges, suggesting that new ways of integrating research perspectives on the geospatial analysis of urban inequalities with the day-to-day practice of urban practitioners and policy makers is required.

Identity and representation matters

Understanding diversities in capabilities, experiences and behaviors is critical in broadening our understanding of urban inequalities and formulating appropriate recommendations to address them. As Franklin et al. (2022:3) state "our claims or assumptions of neutrality and universality in data, methods, models, and applications have hampered our capacity to uncover (analytically and conceptually) the ways in which our research is gendered, age-biased, colour-blind, or global north-centred."

Conclusion and limitations

Whilst we have conducted an extensive review, we acknowledge that the findings expressed in this article do not cover an exhaustive search of all possible literature on inequalities, including important adjacent topics of green and blue infrastructure, health and digital surveillance, labour participation and the gig economy, food deserts and critical GIS scholarship. We reviewed 136 articles to allow for a significant overview, but also engagement with the theoretical contributions of each paper. A different kind of review, with alternative research objectives, may select articles based on very different criteria. For example, the keyword search could incorporate related concepts, specific geographical regions, and emphasize particular themes. Therefore, the scope for future reviews includes explicitly targeting certain contexts, themes such as housing, transportation, health, and the inclusion of related terms such as "fairness."

We believe that the role of future research agendas should be embedded in consolidating existing and developing new concepts, tools, and indicators for improved understanding of the complexity of structural urban inequalities. This includes confronting interdisciplinary barriers to engage a wide range of practitioners and disciplines, from geographical analysis to urban planning and policy making, challenging contextual barriers, across the global north and south. Advancing research agendas on urban inequalities requires expanding multidisciplinarity and trans-disciplinarity approaches. In this way, researchers can support decision-makers and urban practitioners to develop systemic and connected approaches, through iterative assessments and multi-dimensional metrics, to support critical decisions on policy, access and distribution that promote more livable, socially inclusive, and equitable urban environments.

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