

Conceptualising urban inequalities as a complex socio-technical phenomenon

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Abstract

The United Nations World Social Report (2020) documents deep divides within and across countries globally revealing that more than two thirds of the world's population live in countries where urban inequality has increased in the last three decades. Although there is growing recognition of the multi-dimensional effects of urban inequalities, international organisations and governments continue to characterise them as an economic issue, relying on popular, unidimensional indices such as the Gini Index. Through the critical examination of contemporary socio-spatial research centred on urban inequalities, this article advocates an alternative conceptualisation proposing that they are, in fact, a complex socio-technical phenomenon, that arises through multiple spatial and temporal scales out of dynamic interactions between society and critical infrastructure. This critical analysis reveals three predominant lines of research centred on the geo-spatial analysis of urban inequalities from accessibility, distribution and policy and stakeholder perspectives. To engage with the deeper theoretical contributions of these perspectives, a conceptual model of the urban is delineated through a critical reflection on a series of key relational themes and existing debates. A central finding is that socio-spatial perspectives are intrinsic for grasping the deeper systemic and institutional drivers that reproduce urban inequalities.

Key words: urban inequalities, socio-technical systems, geospatial perspectives

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1. Introduction

High levels of inequality have consequences for the social and spatial organisation 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 (SDGs) 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 (World Social Report, 2020:4; Nijman and Wei, 2020).

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 et al., 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). 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; Gianotti et al, 2022), energy poverty (Robinson, 2021), disparities in internet use (Singleton, 2020), digitisation (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, emphasise that the distribution of resources and opportunities across urban territories are not always equal or equitable (Van Wee et al., 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, whilst 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, whilst 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. As the Nobel Laureate in Economics, Amartya Sen (1995) emphasises, it is important to not only identify dimensions of inequalities, but to engage with the broader systemic and contextual factors which drive them. This critical discussion thus aims to consolidate recent findings by identifying different socio-spatial research perspectives and popular methods and metrics, but also to shine light on the socio-technical interactions, feedback loops and processes which reproduce inequalities.

The remainder of this article is structured into four sections (refer to *Figure 1*):

- The first section focuses on developing a descriptive classification of existing socio-spatial perspectives within the geo-spatial analysis of urban inequalities and associated metrics and methods.

- The second section attempts to consolidate the theoretical contributions of these perspectives by proposing a conceptual model of the urban as a complex socio-technical system, drawing on complexity theory.
- The third section presents a critical discussion on socio-technical processes within the urban related to emergent urban inequalities through the identification of key relational trends and insights across the perspectives.
- The final section of this review consolidates the key findings and lays out considerations for future research.

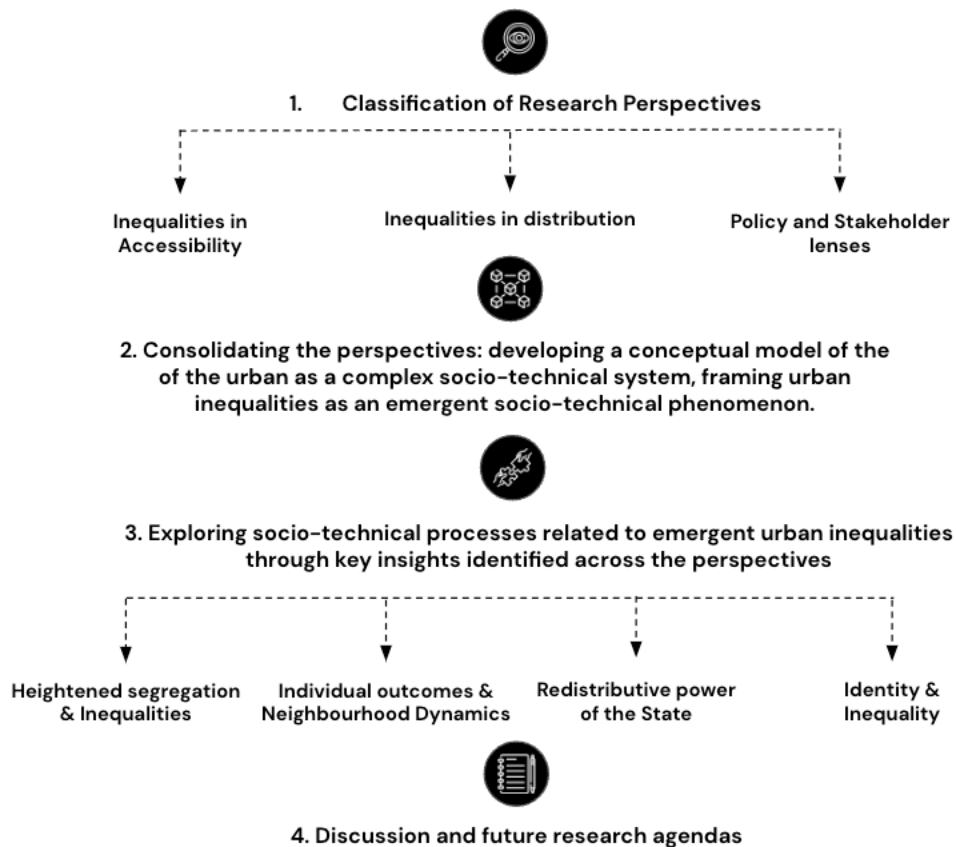


Figure 1: A visual representation of the overarching structure of this article.

This review is based primarily on a keyword-based search, reaped through Scopus, employing the word “inequality”. As “inequality” is a keyword which is employed in a multiplicity of research areas, the initial search was reduced by targeting journals specifically related to urban disciplines and then further narrowed down through a screening process of abstracts and by considering the rating of the journal. This resulted in a total number of 112 texts, which were systematically classified into different perspectives based on their theoretical positioning and choice of metrics. Any additional texts are derived through both backwards and forwards snowballing.

2. Classification of perspectives on urban inequalities

Through the systematic scanning of each paper three predominant perspectives within the analysis of urban inequalities are identified:

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

These perspectives may overlap and are not mutually exclusive. However, for the ease of this comparative discussion, the papers are grouped in this way as are typically centred on different aspects of urban inequalities and associated with specific families of metrics and methods. It is important to identify the perspectives, prior to diving into their theoretical contributions, as each perspective delineates specific areas of focus.

2.1.1 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 et al., 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's 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 et al., 2011). Whilst, 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 socio-economic 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 Chesire, 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 et al.'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 healthcare facilities (Pereira et al., 2021) or employment opportunities (Slovic et al., 2019). These kinds of studies emphasise 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 4.1* 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 emphasise 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.

2.1.2 Popular methods and metrics within accessibility perspectives

Traditional metrics of accessibility derived from transport geography are often utilised within inequalities in accessibility research but are 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 does not 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 Floating Catchment Area Method* (Luo and Wang, 2003), the *Three-Step Float Catchment Area* (Wan et al., 2012), the *Modified Two-Step Floating Catchment Area* (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).

Conversely, traditional inequality metrics derived from Economics may be adapted as a metric for 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 et al., 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. 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.

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.

Table 1: Popular metrics/methods in inequalities in accessibility research

Category	Recent examples	Topic	Metrics
<i>Cumulative + Gravity Measurements</i>	Smith et al. (2020) Anaya-Boig et al. (2022) Luo and Zhao (2021)	Employment Bike sharing High-speed rail	Cumulative travel times Cumulative distance Gravity model
<i>Accessibility Indices</i>	Martinez et al. (2018) Moreno-Monroy et al.(2018) Cohen (2020)	Social Housing Schools Method focused	Composite index Created an index Personal Travel Impact Index
<i>Adapted cumulative + gravity metrics</i>	Giannotti et al. (2021) Pereira et al. (2021) Giannotti et al. (2022)	Transit Healthcare Jobs	2 Step FCA Balanced FCA Adapted Gravity Measure
<i>Adapted economic metrics</i>	Lope and Dolgun (2020). Lucas et al. (2016) Logan et al. (2021)	Trams Method focused Amenities, burdens	Lorenz curve, Gini index Lorenz curve, Gini index Kolm-Pollak EDE

2.2.1 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 et al., 2020), is distributed across geographies of space and time. Depending on the focus of the study, a variety of multi-dimensional variables and scales may be incorporated, in contrast to accessibility perspectives which are generally centred 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 emphasise inequalities that arise out of the distribution patterns of a specific phenomenon. These could be inequalities associated with the distribution of a specific socio-economic 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 centred 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 globalisation (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 emphasise, importantly, that factors driving socio-spatial processes can operate on varying spatial and temporal scales. For example, labour 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 neighbourhood effects is primarily conducted at the scale of the neighbourhood (Nieuwenhuis et al., 2020), refer to *Figure 2*. In fact, the study of neighbourhood effects is a well-defined body of literature on its own. Examples include Chen et al. (2012) who show stagnation in income increases in lower income neighbourhoods in Canadian cities, leading to increases in inter-neighbourhood inequalities between wealthier and poorer neighbourhoods and Patias et al. (2021) who unveil varying pathways of socio-economic change in Britain highlighting neighbourhoods 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.

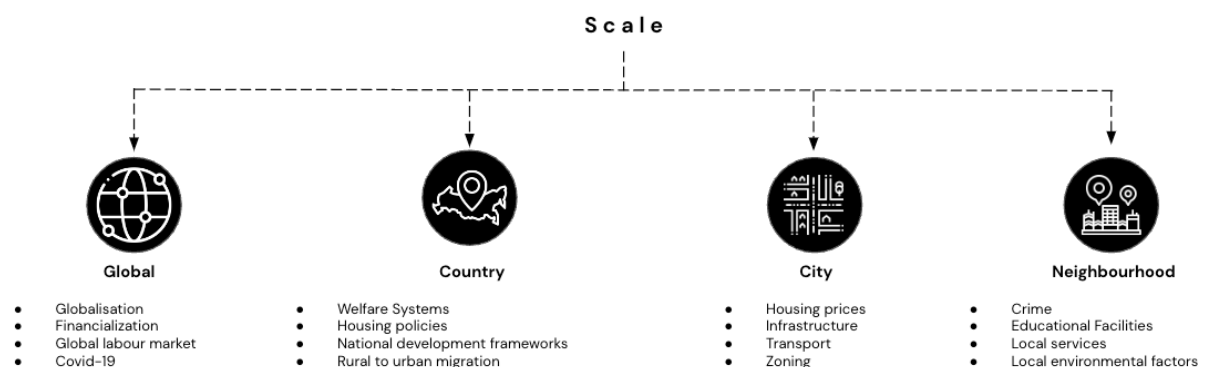


Figure 2: A representation of the multi-scalar nature of different socio-spatial processes.

The contributions of geographical information systems (GIS) to understanding the various facets of these longitudinal, multi-scalar and multi-dimensional processes are diverse. As Delmelle, (2021:2)

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.

2.2.2 Popular methods and metrics within distribution perspectives

Multiple variables and dimensions may be considered when studying inequalities in patterns of distribution. 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 emphasised. Common data reducing techniques include:

- Principal component analysis (PCA) is a technique for reducing the dimensionality of data sets, increasing interpretability, whilst concurrently minimising information loss, as an example refer 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 neighbourhood trajectories which unveil varying pathways of inequalities, e.g., refer to Patias et al. (2021). Sequencing methods originate from genealogy science but are adapted particularly to reduce the trajectory of neighbourhoods to a set of discrete events to classify sequences of change (Delmelle, 2021). Neighbourhoods 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 may 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 “neighbouring” spatial units and their spatial effects. The way in which, a “neighbour” is defined depends on the researcher, it can be based on the positioning of neighbouring 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 theorised spatial interaction.

The predominant methods or metrics employed from this perspective are briefly summarised 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
<i>Spatial auto-correlation</i>	Metz and Burdina (2018) Medina et al. (2020) Li et al. (2020)	Crime Evictions City-regions	Cliff-Ord model Moran's I LISA
<i>Composite indices / matrices</i>	Chen et al. (2012) Nieuwenhuis et al. (2020) Lloyd et al. (2021)	Neighbourhoods Socio-spatial mobility Neighbourhoods	Gini coefficients Deprivation matrix Index of Dissimilarity
<i>Data reducing techniques</i>	Dong (2018) Singleton et al. (2020) Patias et al. (2021)	Rental affordability Digital inequalities Neighbourhoods	PCA Clustering Sequencing
<i>Statistics / Machine learning</i>	Whitworth (2013) Dorling (2010) Molar-Cruz et al. (2022)	Crime Population Urban growth	Spatial regression Descriptive statistics Random Forest

2.3.1 Policy and stakeholder perspectives

The two previous perspectives often highlight the importance of their results for policy makers but are not explicitly centred on specific policies or stakeholders. This perspective directly focuses on urban governance; it is characterised by the fact that specific policies are embedded within institutional contexts and distinct time periods. Research in this area can thus be broadly categorised 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 explain current geo-spatial conditions as a product of 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 funnelled billions of dollars of mortgage credit away from Black neighbourhoods. See *Section 4.2* 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 et al. (2020) also adopt a historically focused approach, suggesting that China's economic policies of capital and labour-intensive growth have led to high productivity clusters centred on mega-cities causing rising inequalities between city-regions. Historical policy analysis highlights how present situations arise out of past decision making.

In contrast, Rodríguez-Pose and Storper (2020) scrutinise 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. Employing a predominantly ethnographic approach Alda-Vidal et al. (2018), conduct a study in Mali that focuses on inequalities within the water supply network of the city of Lilongwe. They engage directly with government workers, showing that due to the belief by government workers that lower income residents can cope better with less water, they prioritise the delivery of water to higher income areas when shortages occur. Studies which focus on contemporary policy, tend to highlight current inequalities for specific stakeholders and are often suggestive of how policy or planning could be altered or enacted differently to address them.

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 et al. (2020). They engage

directly with lower-income residents who reside in outer Portland neighbourhoods, revealing 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. Tomasiello et al. (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 UK households to estimate market effects. Studies with a future policy focus generally address a multitude of potential future scenarios and thus can explore the outcomes of different ones.

2.2.2 Popular methods and metrics within policy and stakeholder perspectives

What separates this perspective methodologically is that it tends to engage directly with key stakeholders and actors. Whilst this kind of research tends to be descriptive in nature, its value lies in the teasing out of underlying, experiential factors which one would be unlikely to capture with a purely quantitative approach, such as previously discussed in Alda-Vidal et al. (2018) ethnographic analysis involving government workers in Lilongwe, Mali. However, problems may arise if this research is one sided and does not represent all the stakeholders' views objectively, thus leading to a potentially biased argument, if not validated by further empirical evidence.

Alternatively, a highly computational approach may be adopted to explore and predict the impacts of future policy scenarios. It is imperative that the computational models are calibrated with real world data to be empirically relevant. Agent based models (ABM) are developed specifically to simulate outcomes as complex processes emerging out of individual decisions and actions (Jackson et al., 2008; Liu and O'Sullivan, 2016). These models can evaluate how certain conditions result in empirically observed situations and they may reveal complex or non-linear effects that result from the collective behaviour of individuals. ABM describe how agents interact and their parameters for processing information and making choices (Blume, 2015). They are useful for demonstrating potential policy outcomes; in particular, they may alert us to emergent consequences of policies centred on things like land use zoning and can be used to test underlying assumptions we make about collective behaviour.

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

Table 3: Popular metrics/methods from Policy and Stakeholder perspectives.

Category	Recent examples	Topic	Metric
<i>Interviews and/or surveys</i>	Cooper and Vanoutrive (2022) Lin and Polsky (2016) Guo et al. (2018)	Ethical frameworks Typhoons Urbanisation	Semi-structured Interviews + surveys Surveys
<i>Stakeholder Engagement/Ethnographic</i>	Tseng and Penning-Rowsell (2012) Mahmoudi et al. (2020) Alda-Vidal et al. (2018)	Flood risks Urban mobility Water Governance	Stakeholder engagement Participatory Ethnographic
<i>GIS Statistics</i>	Faber (2021) Roy et al. (2018) Marsh et al. (2010)	Redlining Spatial segregation Racial inequalities	Digitisation Regression GIS
<i>Agent Based Modelling (ABM)</i>	Tomasiello et al. (2020) Guerrero (2020) Guo et al. (2019)	Social housing Tax + Housing Urban sprawl	ABM ABM ABM

3. Consolidating the perspectives: conceptualising urban inequalities as a complex socio-technical phenomenon that emerge through socio-technical processes

The previous section presents a descriptive classification of contemporary socio-spatial perspectives within the geo-spatial analysis of inequalities. To attempt to engage with the theoretical contributions of the literature, deeper insights into how urban inequalities are reproduced in cities is required. To do this, the subsequent section draws on complexity theory, 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). An examination of the theoretical contribution of each perspective reveals a focus on the interaction between different social and technical components of the city, leading to the development of a conceptual model of the urban as a complex socio-technical system. The central tenet of all geo-spatial analysis of urban inequalities is space and time and this model directly reflects this.

3.1 Introducing a conceptual model of the city as a socio-technical system.

The research perspectives identified in the first section of this review, 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 elements, as opposed to the characteristics of a single element. Indeed, this aligns with thinking around cities as strongly relational systems, in other words cities are systems in which the relations of each element to all other elements are more important for the functioning of the system than the intrinsic properties of the elements themselves (Hillier, 1999). If we embrace the idea that the city is a relational system, we can accept that it is not simply a random collection of elements, but a series of interconnections that are organised to achieve something (Meadows, 2009:11). Systems can be self-organising and are often self-repairing - out of one system other completely new systems can arise (Meadows, 2009:11). Batty (2013) in his book, *The New Science of Cities*, advances this thinking by characterising the city as a complex system; 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.

One approach to develop a conceptual model of the urban, is to abstract the different subsystems that exist within cities (Meerow and Newell, 2016:315). It is proposed that cities are broadly composed of both complex social and critical infrastructure subsystems, with urban inequalities arising as an emergent phenomenon through the dynamic interactions between them over space and time. In this way, cities can be understood as complex socio-technical systems (Hillier, 2012:1). *Figure 3* proposes a conceptual abstraction of the *Social, Spatial, Temporal* and *Critical Infrastructure* subsystems of cities, which are identified across the research perspectives as being theoretically important for understanding urban inequalities.

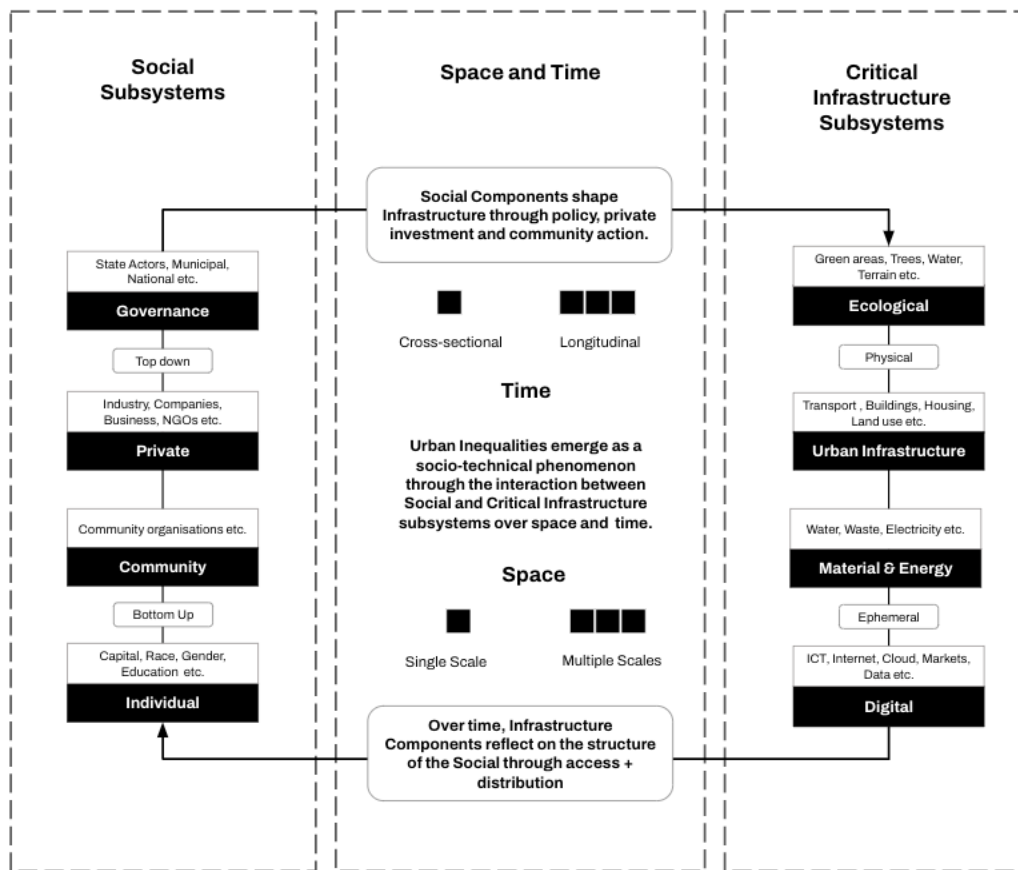


Figure 3: A conceptual model of the urban as a complex socio-technical system, framing urban inequalities as an emergent socio-technical phenomenon that develops over space and time.

3.2 Deconstructing the conceptual model and linking it to the perspectives

The components depicted in *Figure 3* interact within different relational hierarchies. The *Governance networks* are positioned at the top of the *Social*, reflecting their “top-down” influence. Through centralised 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 behaviour 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 behaviour. Community and private organisations, 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*, such as buildings and transportation networks, have direct, material interfaces with the social world.

Evidence suggests that the way that *Critical Infrastructure* and *Social Components* interact is mediated through different spatial and temporal scales. Bettencourt (2014.b) 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. Urbanisation 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 Hansen (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 neighbourhoods 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 2*, usually focus on the interaction between two or more of the subsystems represented in *Figure 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 socio-economic group. Whereas *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 et al'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 *Figure 3*.

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 how socio-technical processes 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 research perspectives.

4. Social technical processes that reproduce urban inequalities: a critical discussion of key relational insights that reflect on the theoretical contributions of geographical analysis

Further interrogation of the conceptual model presented in Section 3, leads to a discussion on the following set of key relational trends and theoretical insights:

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

4.1 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. Whilst 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 US metropolitan areas. They argue that increasing differences in purchasing power ultimately determine the housing pools people can access, which is resulting in increasing polarisation of households in separate residential areas. Similarly, Chen et al. (2012) suggests 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 1991–2010, rising income inequalities contributed to the development of residential segregation by income. Whereas 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 neighbourhoods.

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 neighbourhoods 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, emphasising that social housing zoning policies have served to reinforce spatial mismatch through being placed in peripheral locations far from employment opportunities. Whereas Singleton et al. (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 neighbourhoods. 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 emphasise 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) emphasise how changing housing market conditions are fuelling processes of gentrification in London, driving lower income population groups out of centrally located areas and increasing their travel costs. Institutional processes are also emphasised 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, 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 polarisation through disconnection between aspects of the social and critical infrastructure subsystems (Singleton et al., 2020; Martinez et al., 2020; Slovic et al., 2019).

4.2 The relationship between individual outcomes and neighbourhood dynamics

The relation between individual outcomes and neighbourhood 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 neighbourhoods on individual outcomes has been an area of interest since Wilson (1987) study on concentrated poverty in African American ghettos in the United States. A wide range of theoretical developments followed, with evidence supporting, on the one hand, that individuals influence and shape neighbourhood environments, but on the other hand, that the socio-spatial characteristics of neighbourhoods, can also shape individual life path courses.

Manley et al. (2011) suggest that individuals do not locate themselves randomly across neighbourhoods 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 neighbourhoods 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 neighbourhoods that are beyond the reach of low-income households (Cheshire, 2012). Therefore, financial limitations have an impact on the selection of neighbourhoods available to the individual.

There is increasing evidence that the communal sharing of localised 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 US dollars away from minority neighbourhoods in the USA, previously touched on in *Section 2.3.1*. 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, a 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.

Untangling causality is empirically challenging and may even be impossible. Whilst individuals to a certain degree decide which neighbourhoods they reside in, their purchasing power can seriously limit these decisions (Manley et al., 2011). Neighbourhood effects are inherently contextually dependent as they relate to specific social, institutional, and spatial characteristics of a specific neighbourhood. As the studies discussed in this section note, a certain behaviour is not produced by a certain neighbourhood, but there are impacts and increasing longitudinal studies which 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 *Figure 3*.

4.3 The relationship between rising inequalities and the re-distributive 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 liberalisation 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 40-100 % 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 United States. 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 polarisation 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) reveals rising number of evictions in the USA, showing how a lack of affordable housing options is leading to increasing housing insecurity. Conversely in the global South, taking into consideration a complex colonial history under which few social housing programs existed, social housing has predominantly been in the form of subsidised housing. Many of these subsidised homes are located and have been zoned to cheap land in peripheral zones, such as been the case with many of the RDP homes in South Africa (State of the South African Cities Report, 2016) and Infonavit scheme in Mexico (Aguilera, 2016), which creates an environment prime for economic polarisation.

Whitworth (2022) argues neoliberalism has gone hand in hand with processes of Globalisation leading to blanket policies that emphasise the free market, privatisation, and deregulation which in turn has diminished the re-distributive 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).

4.4 The intersection of identity and inequalities in space

Identity can be thought of as the qualities, beliefs, personality traits, appearance or expressions that characterise 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 *Figure 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 (labour 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 neighbourhoods 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. Whereas 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 neighbourhoods are excluded from incorporation into municipal boundaries, resulting in political and material disadvantages (Marsh et al., 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 et al. (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 enrol 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 institutionalises 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 theorised 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 et al., 2018).

5. Discussion and research agenda

This article has included the review and critical reflection of over 112 publications. In summary, it makes three primary contributions:

- Firstly, a multi-disciplinary classification of contemporary socio-spatial research perspectives on the geographical analysis of urban inequalities leading to the identification of three predominant viewpoints: *accessibility*, *distribution*, and *policy and stakeholder perspectives*.
- Secondly, an examination of the theoretical contribution of each lens reveals a focus on the interaction between different social and technical components of the city, leading to the development of a conceptual model of the urban as a complex socio-technical system, as depicted in *Figure 3*.
- Finally, the relations between the components in this complex system are further explored through a critical discussion of key, relational urban themes identified across the literature. These discussions reveal divergent viewpoints which emphasise 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:

1. *From economic to multi-dimensional 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 et al., 2021). Whilst the geo-spatial 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 multi-dimensional thinking needs to be placed at the heart of the debate.

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

The literature regularly emphasises 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. Whereas, the conceptual model as proposed in *Figure 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, 2001:5). The complexity of interactions, interdependencies, and emergent properties within a city increase as its scale increases (Bettencourt, 2014.b). Feedbacks and non-linearities between its components lead to uncertainties as it dynamically changes (Batty, 2014). Therefore, time and scale become key considerations, invoking important questions around the spatial (street, neighbourhood, city), and temporal (tactical, long term or phased) scales of interventions or policies that attempt to address urban inequalities.

3. *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 et al, 2018:282). Understanding complex urban systems requires insight into the formation and relations between its array of subsystems. Conceptualising 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.

4. *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 non-linearities which create uncertainties (Walloth et al, 2014). Attempts need to be made to move away from normative theories of urban development which disregard the diverse needs and behaviour 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 geo-spatial analysis of urban inequalities with the day-to-day practice of urban practitioners and policy makers is required.

5. *Identity and representation matters*

Understanding diversities in capabilities, experiences and behaviours 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”.

Limitations and conclusion

Whilst we have conducted an extensive review of the literature, it is by no means an exhaustive search, thus there is an acknowledgement that the findings expressed within this review are inherently bound within the confines of the articles reviewed. 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 multi-disciplinarity 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 liveable, socially inclusive, and equitable urban environments.

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