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UNEQUAL CITIES

An investigation into the reproduction of urban inequalities through socio-technical processes and policy.

Ruth Joan Nelson

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Unequal Cities:
An investigation into the reproduction of urban inequalities through socio-technical processes and policy.

Dissertation

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by

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I dedicate this dissertation to the rights of urban citizens everywhere. Every citizen deserves the opportunity to influence, enjoy, thrive and shape their city to their heart's desire, and in doing so, shape their life.

Ruth Nelson

Summary

Contextualising the Problem

Seventy percent of the world's population live in countries where inequalities have increased in the last three decades. Understandings of inequalities have traditionally been based on economic and class-based factors which have informed popular metrics of inequality, adopted by governments and large organisations around the world. There is a growing recognition that global understandings of inequality must be combined with empirically grounded, context-sensitive analyses. Theoretical advancements, particularly within urban studies, are leading to renewed understanding of inequalities as a multidimensional problem, which is not only *expressed* through, but *exacerbated* by urbanisation processes. Concurrently, spatial data science is allowing for the specific consideration of spatial and temporal factors related to infrastructure, demography and spatial characteristics. It is an emerging interdisciplinary field which not only combines geography, data science, and computational methods to analyse diverse spatial data sources, but also raises critical questions about how data is produced, interpreted, and applied. Spatial data science has the potential to support more context-sensitive approaches to studying inequalities, but its application must be critically examined.

Approach

The overarching research objective is to advance understandings of the underlying structural drivers that reproduce urban inequalities by combining critical theoretical insights with contextually grounded empirical analyses offered by spatial data science methods. I draw on a complex systems approach which recognises that inequalities are, by their very nature, difficult to describe, reinforced by feedback dynamics between relational components and are not linear in cause and effect.

In *Chapter 2* I integrate geospatial analysis of inequalities with complexity science to develop an overarching theoretical framework that conceptualises urban inequalities as a complex socio-technical phenomenon. This serves as the theoretical foundation for the three diverse, empirical studies in the subsequent chapters. Each are framed temporally, addressing the **past, present**, and **future** of urban inequalities:

- The first empirical study in *Chapter 3* adopts a **historical and longitudinal** perspective. I examine how inequalities in the **distribution** of housing have evolved in response to shifts in policy over time, focusing on neighbourhoods in Rotterdam, Netherlands. I employ geo-demographic classification, sequence analysis, and policy evaluation methods to combine insights from the analyses of local neighbourhood development and the evolution of national housing policies.

- The second empirical study, in *Chapter 4*, is **present-oriented**. I evaluate current neighbourhood **access** to places of employment across cases in both the global North and South, namely the City of Cape Town, South Africa, Rotterdam and the Hague, Netherlands and Monterrey, Mexico. The major contribution of this chapter is the operationalisation of multiple ethical perspectives drawn from moral and political philosophy into measurements of spatial justice for accessibility within a single comparative framework, referred to as Mapping Accessibility for Ethically Informed Planning (MAP).

- The third empirical study, in *Chapter 5*, is **future-oriented**. I collectively develop transport scenarios through stakeholder engagement by analysing a number of parameters that have been identified as significant **policy** levers in Cape Town, South Africa. The study moves beyond an interdisciplinary approach towards transdisciplinary research by not only drawing on transport

scenario planning, spatial network analysis and policy analysis, but also directly engaging with policymakers, citizens, and academics to explore strategic interventions contributing to debates on equitable urban futures.

Scientific and Societal Contributions

This dissertation advances understanding of the structural drivers of urban inequalities through integrating critical theory with spatial data science. In Chapter 2, I develop a new theoretical framework for urban inequalities. This framework serves as a critical foundation for the subsequent three empirical case studies drawn from both the global North and South in Chapters 3-5. By bridging critical theoretical insights with novel empirical methods, I contribute methodologically and theoretically to debates across multiple disciplines, including but not limited to urban studies, geographical analysis, computational social sciences and transportation.

I extend these debates beyond academia, by engaging directly with stakeholders and policy. From this research, I identify three pathways which reproduce unequal cities: unequal distribution of housing, unequal access to amenities and fragmented governance and weak community agency. Each of these pathways is interrelated, and the deepening disparities that characterise many cities stem from the combination of these factors. Based on these pathways, I develop 6 principles which can be applied within urban governance to mitigate unequal cities.

Samenvatting

Contextuele probleemanalyse

Zeventig procent van de wereldbevolking woont in landen waar de ongelijkheden tussen mensen de afgelopen drie decennia zijn toegenomen. Begrippen over ongelijkheid zijn traditioneel gebaseerd op economische en klassenverschillen, die de gangbare meetmethoden van ongelijkheid vormen en wereldwijd worden gebruikt door overheden en grote organisaties. Er is steeds meer erkenning dat globale inzichten in ongelijkheid gecombineerd moeten worden met empirisch onderbouwde, contextspecifieke analyses. Theoretische ontwikkelingen, vooral binnen de stedelijke studies, leiden tot een vernieuwd begrip van ongelijkheid als een multidimensionaal probleem dat niet alleen *tot uitdrukking komt* via stedelijke processen, maar er ook *door verergerd* wordt. Tegelijkertijd maakt ruimtelijke datawetenschap het mogelijk om specifieke ruimtelijke en temporele factoren rondom infrastructuur, demografie en ruimtelijke kenmerken te onderzoeken. Dit opkomende interdisciplinair vakgebied combineert geografie, datawetenschap en computationele methoden om diverse ruimtelijke databronnen te analyseren en stelt daarnaast kritische vragen over hoe data wordt geproduceerd, geïnterpreteerd en toegepast. Ruimtelijke datawetenschap heeft de potentie om contextgevoeliger onderzoek naar ongelijkheid te ondersteunen, maar de toepassing ervan vereist een kritische benadering.

Aanpak

Het hoofddoel van dit onderzoek is het vergroten van het inzicht in de structurele oorzaken die stedelijke ongelijkheid in stand houden, door kritische theoretische inzichten te combineren met contextueel verankerde empirische analyses, mogelijk gemaakt door ruimtelijke datawetenschappelijke methoden. Ik maak gebruik van een benadering vanuit complexe systemen, die erkent dat ongelijkheden van nature moeilijk te vatten zijn, versterkt worden door feedbackmechanismen tussen onderling verbonden componenten, en niet lineair zijn in oorzaak en gevolg. In *Hoofdstuk 2* verbind ik georuimtelijke analyses van ongelijkheid met complexiteitswetenschap om een overkoepelend theoretisch kader te ontwikkelen waarin stedelijke ongelijkheden worden gezien als een complex sociaal-technisch fenomeen. Dit vormt de theoretische basis voor de drie empirische studies in de volgende hoofdstukken. Deze studies zijn elk temporeel georiënteerd en behandelen het **verleden**, **heden** en de **toekomst** van stedelijke ongelijkheden:

- De eerste empirische studie in *Hoofdstuk 3* kijkt **historisch en longitudinaal** naar hoe ongelijkheden in de **woningverdeling** zich ontwikkeld hebben door beleidsveranderingen over de tijd, met een focus op wijken in Rotterdam, Nederland. Ik gebruik geo-demografische classificatie, sequentieanalyse en beleidsevaluatie om inzichten te combineren vanuit de analyse van lokale wijkontwikkeling en nationale huisvestingspolitiek.

- De tweede empirische studie in *Hoofdstuk 4* is gericht op het **heden**. Ik analyseer de huidige wijktoegang tot werkgelegenheid in cases uit zowel het mondiale Noorden als Zuiden, namelijk Kaapstad (Zuid-Afrika), Rotterdam en Den Haag (Nederland) en Monterrey (Mexico). De belangrijkste bijdrage is het operationaliseren van meerdere ethische perspectieven uit de moraal- en politieke filosofie in metingen van ruimtelijke rechtvaardigheid binnen één vergelijkend kader, genaamd Mapping Accessibility for Ethically Informed Planning (MAP).

- De derde empirische studie in *Hoofdstuk 5* kijkt **toekomstgericht**. Samen met stakeholders ontwikkel ik transportscenario's door een aantal belangrijke beleidsparameters te analyseren in Kaapstad, Zuid-Afrika. Deze studie gaat verder dan interdisciplinair onderzoek en streeft transdisciplinariteit na door transportscenario-planning, ruimtelijke netwerkanalyse en beleidsevalu-

atie te combineren met directe betrokkenheid van beleidsmakers, burgers en wetenschappers om strategische interventies te verkennen die bijdragen aan een rechtvaardige stedelijke toekomst.

Wetenschappelijke en Maatschappelijke Bijdragen

Dit proefschrift draagt bij aan het begrip van de structurele oorzaken van stedelijke ongelijkheid door kritische theorie te integreren met ruimtelijke datawetenschap. In Hoofdstuk 2 ontwikkel ik een nieuw theoretisch kader voor stedelijke ongelijkheden. Dit kader vormt de kritische basis voor de drie empirische casestudies uit zowel het mondiale Noorden als Zuiden in Hoofdstukken 3-5. Door kritische theoretische inzichten te verbinden met vernieuwende empirische methoden, lever ik methodologische en theoretische bijdragen aan debatten in diverse disciplines zoals stedelijke studies, geografische analyse, computationele sociale wetenschappen en transportonderzoek.

Daarnaast breid ik deze discussies buiten de academie uit door direct samen te werken met stakeholders en beleidsmakers. Vanuit dit onderzoek identificeer ik drie mechanismen die ongelijkheid in steden in stand houden: ongelijke woningverdeling, ongelijke toegang tot voorzieningen en gefragmenteerd bestuur met een zwakke gemeenschapspositie. Deze mechanismen zijn met elkaar verweven en de groeiende ongelijkheden in veel steden zijn het resultaat van hun samenspel. Op basis hiervan formuleer ik zes principes die kunnen worden toegepast in stedelijk bestuur om ongelijkheid te verminderen

Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world and with each other.

– Paulo Freire

Contents

Introduction

This chapter outlines the motivation of the research, a brief theoretical background covering this dissertation's key concepts, the main research gap, overarching approach, research questions and overview of this dissertation.

"The problems that scientists and engineers have usually focused upon are mostly "tame" or "benign" ones... For each the mission is clear... Wicked problems, in contrast, have neither of these clarifying traits; and they include nearly all public policy issues... We are calling them "wicked" not because these properties are themselves ethically deplorable... But then, you may agree that it becomes morally objectionable for the planner to treat a wicked problem as though it were a tame one..., or to refuse to recognise the inherent wickedness of social problems."

– Rittel and Webber (1973:160)

1.1 Background

Urban inequalities are among the most critical challenges cities face today (Tonkiss, 2020). The World Inequality Report (2022) reveals that the richest 10% of the global population currently appropriate 52% of all global income. Global wealth inequalities are even more pronounced, with the poorest 50% of the population possessing merely 2% of total wealth, in contrast to the richest 10% who currently own 76% of all wealth (World Inequality Report, 2022:3). As Saskia Sassen (2014:14), renowned Author and Chair of Sociology at Columbia University notes, "Concentration at the top is nothing new. What concerns me is the extreme forms it takes today in more and more domains across a good part of the world."

Until recently, dominant discourse on inequality has primarily emphasised socio-economic dimensions (Yap et al., 2021). Whilst sociological traditions have long explored inequality as a consequence of class-based conditions rooted in economic, cultural, and educational factors (Weber, 1972; Bourdieu, 2001; Goldthorpe and Jackson, 2007), economic perspectives focus on disparities in the distribution of wealth and income (Smith, 2007 (originally 1776); Kuznets, 1955; Milanovic, 2005; Milanovic, 2016). Economic approaches have gained global traction, particularly through the use of quantitative indices, such as the Gini Index[1], Theil Index[2], Atkinson Index[3] and Palma Ratio[4]. While these indices are useful in quantifying and identifying who experiences income inequality, they fall short in addressing the structural mechanisms that underpin inequality (Guidetti and Rehbein, 2014; Wolff and De Shalit, 2023). Moreover, both sociological and economic approaches often adopt universal, Eurocentric frameworks that marginalise spatial geographies by overlooking the specific histories and experiences of populations, particularly in the global South (Guidetti and Rehbein, 2014:3). There is growing recognition that global understandings of inequality must be complemented by empirically grounded, context-sensitive analyses (Rehbein, 2011; Parnell and Robinson, 2012; Pieterse, 2019).

The role of location and space is increasingly being understood as fundamental to understanding inequalities (Milanovic, 2016). Theoretical advancements, particularly within urban studies, are leading to renewed understandings of inequalities as a multidimensional problem, which is not only *expressed through*, but *exacerbated by* urbanisation processes[5] (Harding and Blokland, 2014). A number of urban theorists link rising urban inequalities to the adoption of neoliberal policies and practices (Brenner and Theodore, 2005; Harvey, 2008; Peck et al., 2009). Cities often implement such policies with the goal of achieving universal benefits through economic growth. However, critics argue that this approach is rooted in economic models that assume spatial and demographic uniformity. They focus on maximising overall economic growth, and less on the distribution of that growth, often leading to unintended consequences - chiefly, the worsening of inequalities between populations and regions (Harvey, 2019). Alternative perspectives shine light on the relationship between inequalities and local urban processes and practices (Robinson, 2016; Franklin et al., 2022). These perspectives usually focus on the everyday interactions between local residents and the unequal distribution of public resources, such as housing, education, healthcare, information, and transport infrastructure (Lucas, 2012). Within urban accessibility research this has evolved into critical engagement with theories in political and moral philosophy to frame what justice means for both the distribution of critical infrastructure and processes of decision making which shape it (Pereira et al., 2017; Van Wee and Mouter, 2021). Overall, various critical urban debates are expanding our understanding of urban inequalities as an explicitly relational, multi-scalar and spatial-temporal phenomenon which emerges between the intersection of people, place, and infrastructure.

[1] https://www.census.gov/topics/income-poverty/income-inequality/about/metrics/gini-index.html
[2] https://www.census.gov/topics/income-poverty/income-inequality/about/metrics/theil-index.html
[3] https://www.census.gov/topics/income-poverty/income-inequality/about/metrics/atkinson-index.html
[4] https://www.econ.cam.ac.uk/news/palma-oct-13.html
[5] *Urbanisation* may be defined as a process of change from rural to urban ways of living, associated with fundamental demographic, economic and social transformations (Nations, 2018)

Concurrently, methodological advancements in spatial data science are allowing for the explicit consideration of spatial-temporal dimensions of inequalities. Recent empirical research demonstrates the potential for these methods to quantitatively model and visualise inequalities across diverse thematic areas, including digital access, housing, and energy (Robinson, 2019; Singleton et al., 2020). Nevertheless, whilst these methods are often framed as objective and neutral, they are inherently shaped by the ideas, instruments, practices, and knowledges that underpin data production and analysis (Kitchin et al., 2015:16). This has significant implications for the way data is interpreted, particularly in the analysis of urban inequalities. Interpretation is not merely technical; it is a cognitive process that relies on contextual understanding to uncover the systemic drivers behind observed spatial patterns (Kandt and Batty, 2021:7). Without critical reflection and theoretically informed interpretation, researchers risk reproducing outdated normative assumptions that fail to account for the needs of diverse populations and regions (Franklin et al., 2022). Thus, a key challenge is integrating these methods with appropriate theoretical frameworks to generate actionable insights for addressing urban inequalities.

The overarching research aim of this work is to advance understandings of the underlying structural drivers that reproduce urban inequalities by combining critical theoretical insights with contextually grounded empirical analyses offered by spatial data science methods. I draw on a complex systems approach which recognises that inequalities are by their very nature difficult to describe (de Roo et al., 2020:2), reinforced by feedback dynamics between relational components and are not linear in cause and effect (Alexander, 2020:19). Throughout, I contribute methodologically and theoretically to debates across multiple disciplines, including but not limited to urban studies, geographical analysis, computational social sciences and transportation. I extend these debates beyond academic disciplines, by engaging with stakeholders and policy.

In *Chapter 2* I integrate the geospatial analysis of inequalities with complexity science to develop an overarching theoretical framework that conceptualises urban inequalities as a complex socio-technical phenomenon. This serves as the theoretical foundation for the three diverse, empirical studies in the subsequent chapters. These studies are framed temporally, addressing the **past, present**, and **future** of urban inequalities. The first empirical study in *Chapter 3* adopts a **historical and longitudinal** perspective. I examine how inequalities in the **distribution** of housing have evolved in response to shifts in policy over time, focusing on neighbourhoods in Rotterdam, Netherlands. I employ geodemographic classification (Voas and Williamson, 2001), sequence analysis (Kang et al., 2020), and policy evaluation methods (Hermans and Thissen, 2009) to combine insights from the analyses of local neighbourhood development and the evolution of national housing policies. The second empirical study, in *Chapter 4*, is **present-oriented**. I evaluate current neighbourhood **access** to places of employment across cases in both the global North and South, namely the City of Cape Town, South Africa, Rotterdam and the Hague, Netherlands and Monterrey, Mexico. The major contribution of this chapter is the operationalisation of multiple ethical perspectives drawn from moral and political philosophy into measurements of spatial justice for accessibility within a single comparative framework. The third empirical study, in *Chapter 5*, is **future-oriented**. I collectively develop transport scenarios through stakeholder engagement by analysing a number of parameters that have been identified as significant **policy** levers in Cape Town, South Africa. The study moves beyond an interdisciplinary approach towards transdisciplinary research by not only drawing on transport scenario planning (Lyons et al., 2021), spatial network analysis (Luo et al., 2019) and policy analysis (Hermans and Thissen, 2009), but also directly engaging with policymakers, citizens, and academics to explore strategic interventions contributing to debates on equitable urban futures.

In this chapter I provide a brief introduction to urban theory on inequalities, identify the central research aim, articulate the key research questions and overaching approach. I conclude with an overview of the dissertation structure, explaining how each chapter contributes to a deeper under-

standing of how urban inequalities are reproduced over space and time.

1.2 An introduction to urban theory on inequalities

Whilst urbanisation takes place in a variety of ways, some coherent trends have emerged in the relationship between urbanisation and inequality. I will provide a brief overview of these trends as they cover key theoretical ideas which inform this work.

The World Inequality Report (2022) shows that the period from 1945 till 1980, was an era of shrinking inequality in many parts of the world, including the USA, UK, France, but also India and China. The reasons behind this, according to the report, relate to policy, the fact that tax rates were high, and that there was an overarching ideology that inequality needed to be kept in check (World Inequality Report, 2022:3).

Today, most governments could not engage in the large-scale infrastructure projects which drove urbanisation in the postwar decades (Sassen, 2014:21). Through widespread programs of deregulation and liberalisation, there has been unprecedented growth in the private wealth of global financial institutions (Sassen, 2014). Global Debt-to-GDP ratios have been on the rise for several decades, with the largest debts being in *low-income countries* (IMF, 2023). As a result, many countries pay more to their lenders than they invest in basic components of development such as health and education (Sassen, 2014:27).

Graham and Marvin (2001) theorise that as a consequence of neoliberal policies, many cities are experiencing a mode of urban development they refer to as "splintering urbanism". They define splintering urbanism as an urbanisation process that prioritises infrastructure expansion (e.g., transport, electricity, roads) in already well-developed, 'low-risk' areas. In turn, less-developed areas, deemed 'higher risk' investments, are systematically bypassed. Over time, spatial polarisation intensifies as investment is repeatedly concentrated in certain areas, whilst others are persistently "left behind". This persistent neglect exacerbates deprivation across social, political, environmental, and cultural dimensions (Pike et al., 2024).

In many global South countries, particularly on the African continent, this is set against a long history of colonial practices. The colonial state inherently prioritised certain areas and marginalised others (Graham and Marvin, 2001:82). Underpinning this mode of development were ideologies of race, class, and culture which governed who should be in the city and where they could reside (Myers, 2011:53). It is well documented that colonial-era spatial planning paradigms continue to exacerbate socio-spatial inequalities in African cities (Kombe et al., 2022). Colonial zoning and land use planning regulations continue to disproportionately disadvantage lower-income households while ensuring better services for middle- and high-income groups. This underscores the significance of historical development patterns and entrenched planning structures in reinforcing urban inequalities.

Housing crises present another trend which is receiving increasing attention and theoretical debate. The financial crisis of 2008 highlighted how housing is intrinsically tied to the global economy. Madden and Marcuse (2016) argue that local housing markets have been turned into speculative arenas which derive value from scarcity designed to serve global financial capital. As a result, issues related to eviction, gentrification, homelessness and affordability have become hallmarks of modern urbanisation leading to sharp divisions and high levels of segregation across residential neighbourhoods.

Local policies and discriminatory social practices can also intensify neighbourhood segregation. For

1

example, although *redlining*[6] in the United States has been outlawed, research has shown that it has had long-term, intergenerational effects. It has systematically disadvantaged Black populations from entering the housing market (Faber, 2021). In Bangladesh, while the country's laws give men and women equal rights to purchase and own land, in practice, this is limited for women and girls by inheritance rules that are governed by Sharia Law (World Economic Forum, 2017). These examples highlight the unequal effects of urban policies on specific populations.

Up until this point, I have focused on understanding inequalities as a product of economic, social and spatial policy decisions. The structure of society, through policies, economics and culture, are expressed through the spatial structure of cities. However, there is increasing acknowledgement across the social sciences that space also plays a constructive role in creating and sustaining society (Castells, 1996; Hillier and Netto, 2002; Massey, 2005; Sheller, 2017). As a consequence, the spatial organisation of cities is also a factor which can drive urban inequalities in society (Soja, 2010; Tonkiss, 2020). A long body of neighbourhood effects literature focuses on the causal pathways between local environments and individual outcomes. Research by Raj Chetty and his colleagues demonstrate that neighbourhood characteristics significantly influence future earnings, education, and overall economic success (Chetty and Hendren, 2018; Chetty et al., 2022; Bergman et al., 2024). These characteristics include the quality of schools, house prices, crime rates, levels of income inequality, and social segregation (Bergman et al., 2024). This research demonstrates that the socio-spatial characteristics of neighbourhoods shape social mobility by influencing *access to* education, economic opportunities, and public resources.

The benefits of access to substantive opportunities can be linked to Amartya Sen's capabilities framework. Through this framework, Sen (1999) emphasises that development should focus on expanding each person's capability to lead the life they choose by ensuring meaningful access to opportunities which improve their well-being. As such, Sen advocates that income and wealth should not be the primary focus of public policy. Instead, it should focus on intervening to encourage increased access to resources that have the potential to meaningfully uplift people's lives, such as healthcare, education, and socio-economic opportunities.

The effects of geographies of distribution and access on urban inequalities are closely linked to questions of *spatial justice* (Soja, 2010; Fainstein and DeFilipp, 2016). Conceptually, spatial justice encompasses two key dimensions of justice: distributive and procedural (Rocco et al., 2022). Distributive justice concerns the equitable allocation of public resources, while procedural justice examines the processes through which these resources are negotiated, planned, and designed. Harvey (2003) enriches the concept of procedural justice by relating it to broader societal power structures. He advocates for the collective right of citizens to be actively engaged in shaping their cities. Central to this notion is that justice needs to be contextualised. This directly challenges neoliberal modes of urbanisation driven by foreign capital and private enterprises, which often displaces and disenfranchises local residents.

In summary, this brief discussion emphasises that urban inequalities are a systemic issue which manifest across many dimensions of socio-spatial well-being. Many urban scholars emphasise the role of economic, spatial and social policy in reinforcing inequalities. Critics of neo-liberal policies link them to increasing spatial polarisation. In the global South, inherited colonial spatial planning practices further intensify inequalities. Another key theoretical debate focuses on the effects of the financialisation and globalisation of housing. In addition to these perspectives, others examine how the spatial organisation of cities has the potential to perpetuate inequalities (Fainstein and DeFilipp, 2016). Neighbourhood effects research explores how local dynamics and shared access to social and infras-

[6] Redlining was a discriminatory practice instituted by the Home Owners' Loan Corporation (HOLC), established in the USA during the Great Depression which had a lasting effect through institutionalising the segregationist practice of denying mortgages to communities of colour (Faber, 2021).

tructural resources influence individual outcomes (Chetty and Hendren, 2018). Benefits derived from access to opportunities provide pathways for people to meaningfully improve their lives. This is inherently related to questions of equality and justice in the city. However, justice extends beyond the equitable distribution of public services and goods; it also encompasses the public's capacity to engage with and drive urban change.

1.3 Research Gap and Aim

The adoption of neoliberal policies has coincided with a widening of inequalities in over two-thirds of countries in the last thirty years (World Inequality Report, 2022). These policies are typically grounded in economic models that often overlook spatial dimensions, particularly the uneven distribution of infrastructure and access to socio-economic opportunities. Moreover, they assume policy neutrality and universal benefit, focusing on overall economic growth and less on the distribution of that growth, disregarding historical context and population heterogeneity (Rehbein, 2011). As a result, the historical legacies and socio-spatial heterogeneity that shape contemporary urban inequalities are routinely overlooked in both policy and economic analysis.

Recent developments in critical urban theory highlights that inequalities are both shaped by and embedded within urbanisation processes (Parnell and Robinson, 2012; Madden and Marcuse, 2016; Tonkiss, 2020). However, advancing this line of inquiry requires moving beyond theory to empirically grounded and reproducible insights. This dissertation seeks to contribute to this agenda by increasing understanding into the structural drivers of urban inequality through an approach that integrates critical theory with spatial data science. Central to this is the construction of a theoretical framework that synthesises geospatial analysis and complexity science, drawing on the work of scholars who highlight the potential of complex systems thinking within urban and geographical analysis (Batty, 2013; Anderson and Dragićević, 2020). This framework is operationalised through iterative application to three empirical case studies drawn from both the global North and South, allowing for a comparative perspective on urban inequalities (Robinson, 2016).

To achieve the objectives set here, I adopt an explicitly transdisciplinary approach by not only drawing on a wide range of scholarly traditions across urban studies, geography, computational social science, and transport research, but also engaging directly with stakeholders to inform policy. By bridging critical theoretical insights with novel empirical methods, the research directly contributes to contemporary debates on urban inequality, offering both conceptual and methodological advances. The design and implementation of this approach are formalised and elaborated in the sections that follow.

1.4 Formalisation of the Research Approach

Spatial data science is an emerging interdisciplinary field that integrates techniques from geographical analysis, and computer and data science. It encompasses statistical, computational, and analytical techniques that leverage new data sources, including satellite imagery, mobile phone data, and real-time sensor networks, along with advances in computational processing power (Singleton and Arribas-Bel, 2019). Key methods include spatial statistics, clustering, GIS, remote sensing, simulation models, network analysis and AI driven analysis (Franklin, 2023). These techniques analyse data on various aspects of the built and social environment, such as street networks, transportation systems, neighbourhood characteristics, and demographic patterns, to identify geographic relationships, patterns, and trends (Kandt and Batty, 2021).

How insights are employed from spatial data science is leading to a range of epistemological and ontological debates (Kitchin et al., 2015). Kitchin et al. (2015) argues for understanding data as an epistemological construct that can be understood through different interpretive frameworks. Rather

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than merely representing reality, he subscribes to a view that data actively shapes and reinforces it (Kitchin et al., 2015:16). D'Ignazio and Klein (2020), in their book *Data Feminism*, takes this argument further, emphasising that data are the products of unequal social relations. They illustrate how data science practices are shaped by how data is collected, processed, analysed, visualised and accessed.

A study published in Bloomberg[7] showed that images produced through the AI model, Stable Diffusion, not only reflected racial and gender inequalities, but amplified them. This issue is not unique to AI-generated imagery, O'Neil (2016) systematically demonstrates how algorithmic decision-making across various fields can disproportionately disadvantage marginalised groups. Unequal power dynamics in data collection, storage, and access are a major concern, particularly given the rapid proliferation of data and its growing impact on larger populations (D'Ignazio, 2017). Critical theoretical frameworks for interpreting, representing, and modelling data are thus essential to prevent the reproduction of existing inequalities in knowledge production (Franklin et al., 2022). Spatial data science has the potential to foster a more context-aware and spatially explicit approach to studying inequalities. However, it is crucial to critically examine how spatial data science is applied, particularly the frameworks, theoretical assumptions, and contextual references that shape its practices.

The overarching research approach is informed by a critical perspective on spatial data science. I aim to integrate critical theoretical approaches with spatial data science by drawing on ideas related to *praxis*, as a foundational research framework. *Praxis* derived from the Greek word for 'action' or 'practice,' refers to the enactment of ideas and theories across various disciplines. In ancient Greek philosophy, Aristotle identified three fundamental human activities: *theoria* (thinking), *poiesis* (making), and *praxis* (doing). He associated praxis with ethical and political activities, emphasising action guided by moral and practical reasoning. Brazilian educator and philosopher Paulo Freire incorporated praxis into his theory of critical pedagogy, defining it as the fusion of reflection and action necessary to challenge and transform oppressive structures (Freire, 1970).

The research approach is centred on shaping a practice of spatial data science to advance knowledge on and inform a course of action to address urban inequalities. As shown in Figure 1.1.a, there is a theoretical component, a spatial data analytics component and a policy and stakeholder component. Through marrying theoretical knowledge of urban inequalities with spatial data methods, frameworks are developed to govern how inequalities are studied through variable selection, analysis, visualisation and interpretation. The results derived from this process suggest a course of action which has implications for stakeholders and policy. Simultaneously, stakeholders and policies may provide critical reflection on theoretical frameworks and inform the applied methods. The process is not linear, and could start with any of the components, as shown by the arrows in Figure 1.1.a.

This dissertation begins by developing an underlying theoretical framework to conceptualise how urban inequalities are reproduced through socio-technical processes over space and time. This underlying framework is then iteratively and reflexively applied to three empirical studies, which leads to the emergence of new theoretical frameworks, methods and tools, as shown in Figure 1.1.b. The first empirical study is longitudinal and **historically** focused, it aims to shine light on the relationship between inequalities in the **distribution** of housing and changes in policy over time across neighbourhoods. The second empirical study is **present** focused and aims to evaluate **current** neighbourhood **access** to places of employment based on specific notions of justice. The final empirical study is **future** focused and aims to develop an approach for planning towards a more just urban future through **policy**. All of the studies also serve as independent academic papers.

[7] https://www.bloomberg.com/graphics/2023-generative-ai-bias/

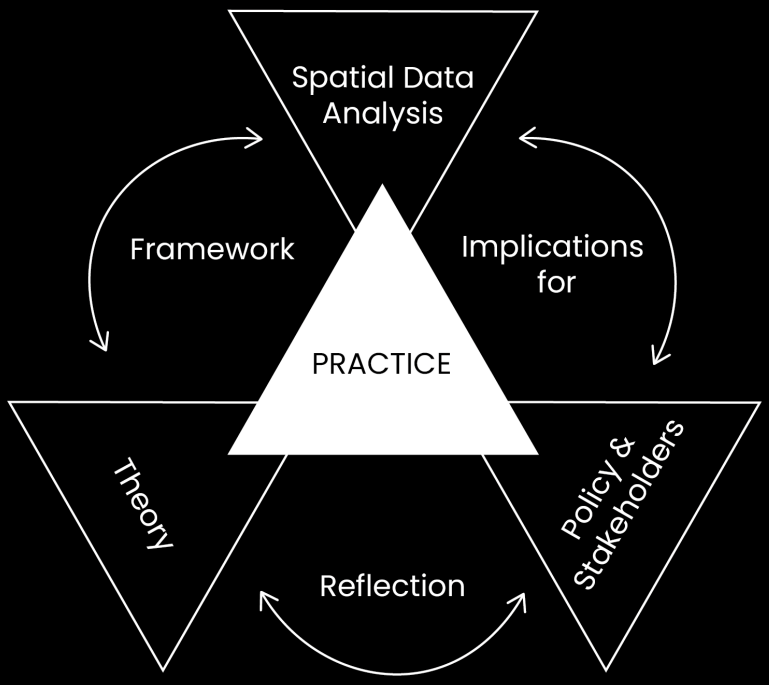

Figure 1.1a: The research approach is centred on shaping a practice of spatial data science to advance knowledge on and inform a course of action to address urban inequalities. There is a theoretical component, a spatial data analytics component and a policy and stakeholder component. The process is not linear, and could start with any of the components.

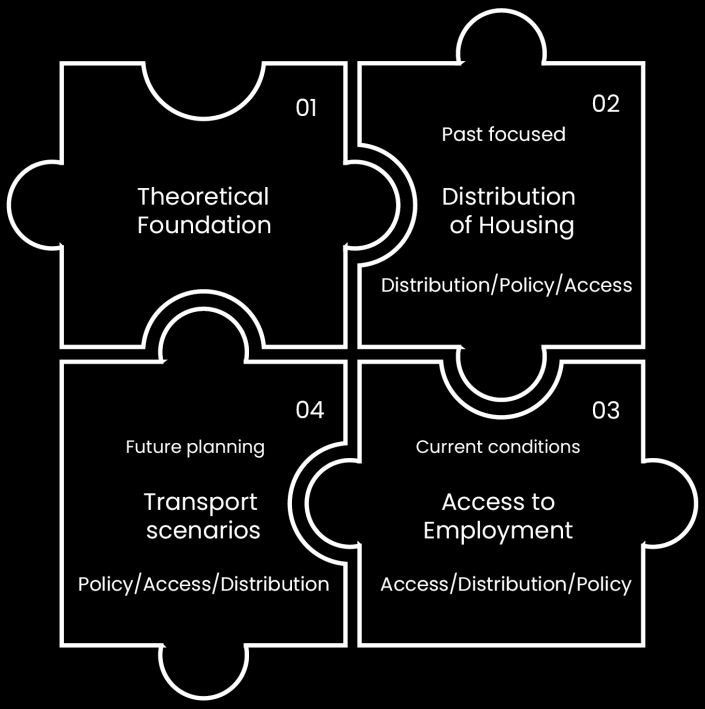

Figure 1.1b: This figure shows the main content sections of this dissertation. The first section focuses on developing a theoretical foundation. The second section focuses on the past, to understand inequalities in the distribution of housing. The third section focuses on assessing current conditions by evaluating access to employment. The fourth section focuses on future planning through transport policy scenarios. Each chapter builds on the findings of the previous chapters.

Figure 1.1

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1.5 Research Questions

With the overarching goal and approach in mind the following explicit research questions are posed:

R1: What underlying perspectives govern the spatial analysis of urban inequalities?

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). Nevertheless, recent methodological advancements are allowing scholars to increasingly apply methods from geospatial analysis to study urban inequalities across a broad range of thematic areas such as housing ownership (Hochstenbach and Arundel, 2019), accessibility to opportunities (Giannotti et al., 2021), energy poverty (Robinson, 2019) and disparities in internet use (Singleton et al., 2020). 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. The aim of this question is to identify underlying perspectives which govern the choice of metrics, variables, and theoretical approaches within the geo-spatial analysis of urban inequalities.

R2: How can the identified perspectives be linked to create an overarching theoretical framework to enhance understanding of the structural urban inequalities?

This question focuses on how the identified perspectives can contribute to an increased understanding of the deeper socio-technical and systemic processes which reproduce inequalities. The aim is to conceive urban inequalities within a wider socio-technical framework that acknowledges the complex nature of them. It is intended to be a starting point for the governing of the way urban inequalities are represented, modelled and interpreted through spatial methods.

R3: How can processes of neighbourhood development be connected to changes in policy to shine light on the structural drivers of inequalities in the distribution of housing?

Changes in policy over the last thirty years have allowed for increased financialisation, deregulation and globalisation of housing. What differentiates real estate from other financial markets is that it possesses a salient socio-spatial geography. Housing inequalities are often framed as an outcome of macroeconomic structural changes or as a product of local socio-spatial conditions, but the interactions between the two are less understood. To develop policies that will effectively target housing inequalities, requires an understanding of both *local and global drivers* of housing inequalities. This necessitates the critical examination of the relationship between the regulation of housing through policy and local socio-spatial neighbourhood characteristics.

R4: How can theories of justice be operationalised to evaluate current neighbourhood accessibility?

Disparities in accessibility make it challenging for people to break out of a cycle of poverty, leading to the reproduction of disadvantages from one generation to the next. A person's accessibility is the social-economic opportunities they derive from their proximity through transport to places such as employment, healthcare and educational facilities. Transportation appraisals are typically based on cost-benefit analysis, which lies in an economic approach that aims to maximise profit. Recent theoretical advancements challenge this approach through giving rise to new conceptual frameworks which link theories of justice from moral and political theory with transportation (Van Wee and Geurs, 2011; Pereira et al., 2017). These advancements emphasise how access is linked to justice and provide conceptual clarity on how different ethical frameworks, when applied to accessibility, may lead to competing values and outcomes. The aim of this question is to operationalise different theories of

justice within a comparative framework to assess current disparities in neighbourhood accessibility to places of employment. It necessitates both an engagement with what justice means and how it can be measured to facilitate its incorporation within planning processes.

R5: How can we plan for a more just transportation future under conditions of uncertainty?

Moving towards a more just future requires thinking about policy which governs access to and the distribution of resources across urban regions and populations. Transport plays a central role in mitigating inequalities by enhancing access to employment, education, and essential services. It is also directly and indirectly related to disparities in housing, neighbourhoods, and health. There are many different factors driving transportation development- such as private investment, policy, and technological change -all of which have high levels of uncertainty. Traditional predictive data science techniques, such as machine learning, may work well when applied to a traditional optimisation engineering problem, but are not suitable for predicting future urban outcomes which have so much uncertainty. How do we plan for a more just future when we cannot fully control that future? This question focuses on developing an approach for shaping cities towards more just outcomes, beyond economic policy.

1.6 Detailed overview of this Dissertation

The contents of each of the remaining parts of this dissertation will be described subsequently. Chapters 2 to 5 answer the research questions and contain the primary results of this work. Table 1.2 contains a visual overview of all the major parts of this dissertation.

Table 1.2: Overview of Chapters

Chapter	Focus	Question/s	Main Methods	Case Studies
1	Introduction			
2	Theory	R1 + R2	Systematic literature review	
3	Historical Distribution	R3	Policy analysis, K-means clustering, sequencing analysis, spatial analysis	Rotterdam, NL
4	Current Access	R4	Complex network analysis accessibility analysis, GIS	Cape Town, SA Rotterdam& the Hague, NL Monterrey, MX
5	Future Policy	R5	Complex network analysis, GIS, stakeholder analysis, Co-creation, Policy analysis	Cape Town, SA
6	Discussion + Conclusion			

Chapter 2 - Conceptualising Urban Inequalities as a Complex Socio-technical Phenomenon

The first two research questions are addressed in Chapter 2 through a systematic literature review centred on the geospatial analysis of urban inequalities. Literature is collected and analysed to identify

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key perspectives and methods. The perspectives are then linked to inform the development of a new theoretical framework for urban inequalities. The framework conceptualises urban inequalities as a complex socio-technical phenomenon by drawing on ideas espoused from complexity science. Rather than focusing on a traditional scientific approach that seeks to increase knowledge through causality, complexity science acknowledges the inherent challenges in defining, solving and understanding complex problems such as urban inequalities (Calenbuhr, 2020). These findings were published in Geographical Analysis[8] in 2024 (Nelson et al., 2024). I have presented this work at multiple conferences and webinars and it has been a crucial theoretical foundation for the subsequent research contributions I make in the study of urban inequalities in the subsequent chapters.

Chapter 3 - Housing Inequalities: the space-time geography of housing policies.

The third research question is examined in Chapter 3 through the development of a methodological framework to connect the analysis of housing policy trends with local socio-spatial trajectories of neighbourhood change. This methodology is applied to the case of Rotterdam in the Netherlands. Although the Netherlands has low levels of income inequality, it has high levels of wealth inequality. One of the primary contributing factors to this is differences in levels of home ownership. The intention of the research is to shine light on the relationship between national housing policy phases, macroeconomic shifts, and local demographic changes. The identification of housing policy phases involved scoping literature to identify, record and visualise them in a multi-scalar timeline. Almost twenty years of multi-dimensional, socio-spatial neighbourhood characteristics were analysed using statistical clustering and sequence analysis. Statistical clustering enables the segmentation of the neighbourhoods into discrete categories based on all of their data. Sequence analysis, when applied alongside clustering, allows for the mapping of neighbourhood transformations as they change between discrete categories over time (Kang et al., 2020). Instead of measuring numerical changes to specific variables across neighbourhoods, sequence analysis evaluates and compares neighbourhoods as holistic trajectories of urban transformations. This research was published in Cities[9]. View a webinar I gave on it here[10].

Chapter 4 – Ethically informed urban planning: measuring distributive spatial justice for neighbourhood accessibility

The fourth research question is addressed in Chapter 4 through the development of a comparative framework, which I refer to as: Mapping Accessibility for Ethically Informed Urban Planning (MAP). Ethical principles have historically been used by philosophers to guide thinking about justice in society. MAP operationalises three alternative metrics of spatial justice based on Egalitarian, Rawlsian and Utilitarian ethical principles. The aim is to allow multiple theories to be compared within a singular framework for debate by stakeholders and citizens. I apply MAP to the diverse case studies of the Metropolitan area of Monterrey in Mexico, the Metropolitan area of Cape Town in South Africa and the polycentric region of the Hague and Rotterdam in the Netherlands to examine neighbourhood accessibility to places of employment. I consider contrasting levels of income inequality as a factor within the case study selection. According to the World Bank, the Netherlands has a Gini Index of 29 (one of the lowest in the world), South Africa 63 (one of the highest in the world) and Mexico 45 (positioned approximately in between the two former cases). I presented this comparative framework at the annual GISRUK 2024 conference in Leeds, UK where my presentation was awarded the best paper award for Spatial Analysis from CASA. A preprint of the paper can be found here[11]. It is currently under review and the supporting code is published open source here[12].

[8] https://onlinelibrary.wiley.com/doi/10.1111/gean.12373
[9] https://www-sciencedirect-com.tudelft.idm.oclc.org/science/article/pii/S0264275123005395?via%3Dihub
[10] https://www.youtube.com/watch?v=2fPqEx9kO9s
[11] https://www.researchsquare.com/article/rs-4293613/v2
[12] https://github.com/RuthJNelson/MAP-Mapping-Accessibility-for-Ethically-Informed-Urban-Planning

Chapter 5 - Envisioning just urban futures: incorporating equity into transport scenario planning.

The fifth research question is interrogated in Chapter 5 through the examination of scenario planning as an approach to understanding different futures and their equity impacts. Building on existing literature, I connect equity of accessibility and transport scenario planning research to explore how equity can be incorporated into scenario planning as a planning support tool, utilising the City of Cape Town (CoCT), in South Africa as a case study. The CoCT is South Africa's second largest city characterised by vast spatial inequalities. In this research, I present four transport scenarios for the CoCT in the form of coherent narratives based on stakeholder engagement through an interactive workshop and semi-structured interviews. To explore the equity impacts of each scenario, they are transformed into representative urban network models. Using the models, accessibility to places of employment is calculated from each neighbourhood and evaluated using a comparative equity framework developed in Chapter 4. Rather than imposing a single ethical framework that may not account for local needs or preferences, I employ a comparative framework to highlight different issues, such as unequal access, lack of access by the socio-economically disadvantaged, or even by the majority of the population. In doing so, I showcase how different ethical frameworks can be operationalised to allow communities to identify their specific priorities and move in a direction that best aligns with their values. Our approach is situated within the broader notion of the Right to the City, as articulated by Harvey (2003), Lefebvre (1968), and others. This concept emphasises the collective power of communities to reshape urbanisation processes. Ultimately, communities and stakeholders must decide how they define justice and equity. A preprint of the paper can be found here[13].

Chapter 6

All of the research questions are revisited in Chapter 6. I reflect on the main findings and their implications for science and policy.

Supplementary Material

The Supplementary Material (SM) includes relevant supplementary material for each chapter and one additional paper, *MAP: Mapping Accessibility for Ethically Informed Urban Planning*, which documents the Python software package produced to support the research in Chapters 4 and 5.

[13]https://papers.ssrn.com/sol3/papers.cfm?abstract$_id = 5141604$

Conceptualising Urban Inequalities as a Complex Socio-technical Phenomenon

This chapter serves as an overarching theoretical foundation for the work presented in this dissertation. It is also intended as a starting point from which the structural drivers of urban inequalities can be analysed by researchers, policymakers and stakeholders. These findings were originally published in Geographical Analysis: Nelson, R., Warnier, M., Verma, T., 2024. Conceptualizing Urban Inequalities as a Complex Socio-Technical Phenomenon. Geographical Analysis 56, 187–216. https://doi.org/10.1111/gean.12373.

Marshall McLuhan (1964) famously said, *"We shape our tools and thereafter our tools shape us"* - the same can be said for cities.

2.1 Introduction

High levels of inequality have consequences for the social and spatial organisation of cities (Modai Snir-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). 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 et al., 2022), energy poverty (Robinson, 2019), disparities in internet use (Singleton et al., 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 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, 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 (Rüttenauer, 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.

Within this chapter we argue for increased integration between the geographical analysis of urban inequalities and complexity science. Whilst many researchers recognise the value in linking geographical analysis with a complex systems approach (Manson and O'Sullivan, 2007; 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 et al., 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 multi-dimensional data sets (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 modelling, but additionally support solutions or results that may not acknowledge trade-offs or underlying structural factors. Therefore, the primary question of this chapter 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?*

2.2 Methodology

2.2.1 Overview

The search strategy, scope, and screening for inclusion of relevant articles is delineated in Section 2.2.2. 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 Section 2.2.3 and in Section 2.2.4, 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.

2.2.2 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 critical examination of their theoretical contributions. Whilst 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 centred 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.

Whilst we acknowledge that there are many related terms to inequality, such as "justice" or "equity", a sufficient number of papers is found within this search term. Subsequently, each of the abstracts are reviewed to ensure that they fall within the scope of the paper. In defining the scope, it is important to recognise 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 et al., 2017). Whereas the term "equality" refers to the distribution of a particular resource or phenomenon, irrespective of moral judgement. 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 Figure 2.2.

2.2.3 Data extraction

Metadata 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.

2.2.4 Data processing

In response to the research question, a three-stage process is developed, which governs the structure of this chapter, refer to Figure 2.2:

The first stage involves examining the excel spreadsheet to ascertain each papers' 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 categorisation. We find three predominant research perspectives based on inequalities in accessibility, distribution, and policy and stakeholder perspectives. Whilst 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 2.3.

The second stage bridges the geospatial perspectives with insights drawn from complexity science in Section 2.4. Whilst many authors within geographical analysis recognise 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 analysing conceptual themes and relational trends across the literature in Section 2.5. The intention of analysing 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 chapter 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.

2.3 Classification of perspectives on urban inequalities

The use of data and digital technologies are at the centre 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,

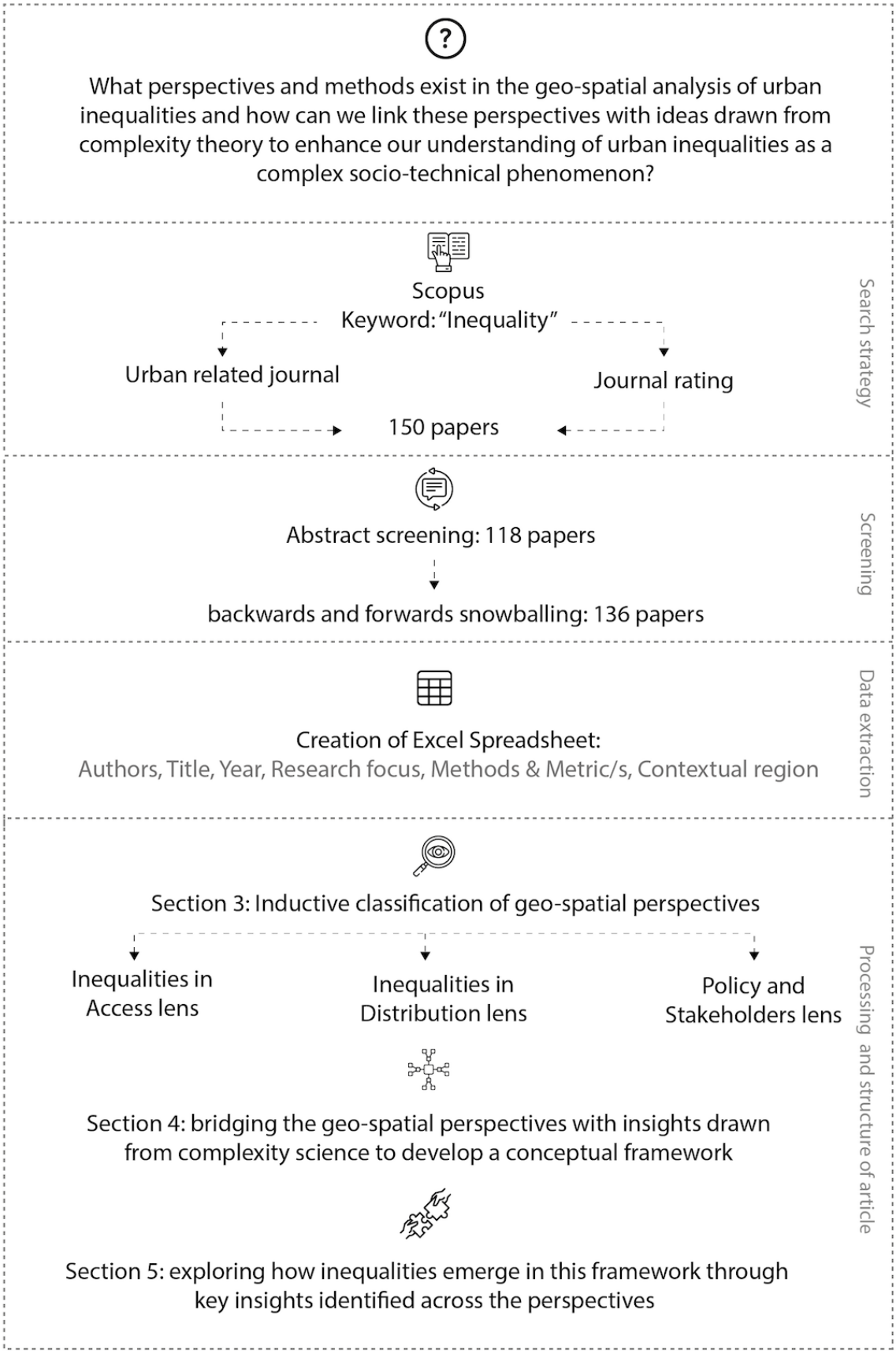


Figure 2.2: A visual representation of the methodological process and structure of this article.

2019). 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 conceptualisation 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 et al., 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 green space (Chen et al., 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 categorisation of each paper into one of three predominant research perspectives. These perspectives may overlap and are not completely mutually exclusive, but in their categorisation 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 recognise different research communities within the field. These perspectives are:

1. Inequalities through an accessibility lens
2. Inequalities through the lens of distribution
3. Inequalities through a policy and stakeholder lens

2.3.1 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 and Geurs, 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 Cheshire, 2014)), or a deficit in existing infrastructure that affects certain populations groups (e.g., such as the physically disabled in Melbourne (Lope and Dolgun, 2020)). Distance is also identified as a potential barrier, as demonstrated by Anaya-Boig et al. (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 2.4.1 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.

Popular methods and metrics within accessibility perspectives

The first branch of metrics of accessibility is derived from transport geography 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).

The second branch of metrics encompasses the adaption of economic 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 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.

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

2.2. 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 2.2: Popular metrics in inequalities in accessibility research.

Category	Recent examples	Topic	Specific Metric
Cumulative + Gravity Measurements	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
Accessibility Indices	Martínez et al. (2018) Moreno-Monroy et al. (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 et al. (2022)	Transit Healthcare Jobs	2 Step Floating Catchment Area Balanced Floating Catchment Area Adapted Gravity Measure
Adapted economic metrics	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

2.3.2 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 (Rüttenauer, 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-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 2.3. 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.

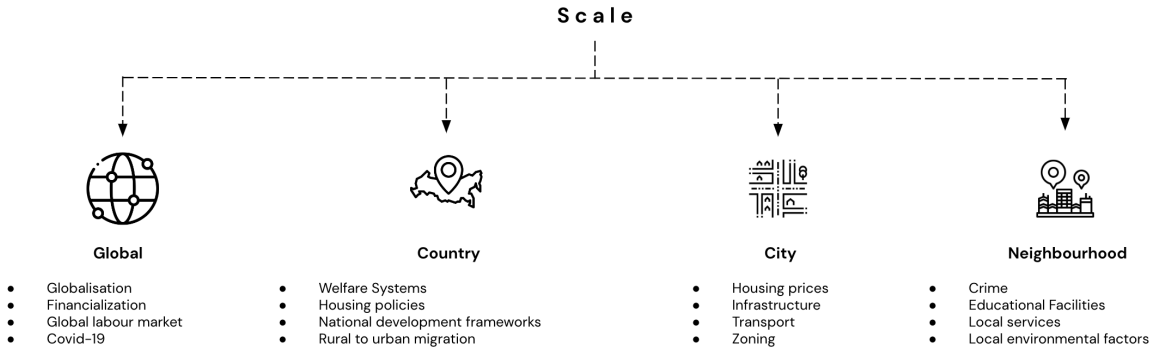


Figure 2.3: A representation of the multi-scalar nature of different socio-spatial processes.

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.

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 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 "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 2.3, if an in-depth account of each of these metrics is required, please refer to the referenced texts.

Table 2.3: Popular metrics in inequalities in distribution perspectives.

Category	Recent examples	Topic	Specific Metric
Spatial auto-correlation	Metz and Burdina (2018) Medina et al. (2020b) Li et al. (2020)	Crime Evictions City-regions	Cliff-Ord model Moran's I LISA
Composite indices/ matrices	Chen et al. (2012) Nieuwenhuis et al. (2020) Lloyd et al. (2021)	Neighbourhoods socio-spatial mobility Neighbourhood change	Gini coefficients; Deprivation matrix Index of dissimilarity
Data reducing techniques	Dong (2018) Singleton et al. (2020) Patias et al. (2021)	Rental affordability Digital inequalities Neighbourhood	PCA Clustering Sequencing
Statistical Analysis/ Machine learning	Whitworth (2013) Dorling (2010) Molar-Cruz et al. (2022)	Crime Population Urban growth	Spatial regression Descriptive statistics Random forest

2.3.3 Policy and stakeholder perspectives

The two previous perspectives often highlight the importance of their results for policy but are not explicitly centred on specific policies or stakeholders. This perspective is characterised 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 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 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 funnelled billions of dollars of mortgage credit away from Black neighbourhoods. See Section 2.4.2 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 urban inequalities arise out of past decision-making processes, shedding light on path dependencies.

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. 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 et al., 2018). Direct engagement with municipal workers reveals that they believe lower income residents can cope better with less water, therefore they prioritise 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 et al. (2020) building on critical GIS insights. They combine digitized spatial data from participatory mapping exercises with lower-income residents who reside in outer Portland neighbourhoods. 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. Whereas, 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 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 et al. (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. Whilst 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 recognise 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 et al. (2019) simulate urban development patterns using an agent-based model, to understand if policy is needed to regulate the relationship between urban sprawl and income segregation. 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 particularly useful for demonstrating potential policy outcomes; testing underlying assumptions and alerting us to emergent consequences of policies centred on things like land use zoning.

The predominant methods or metrics used within this perspective are summarised in Table 2.4.

Table 2.4: Popular metrics from a Policy and Stakeholder perspective.

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

2.3.4 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). Data sets 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.

Whilst, 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 analyse them (Lauribault, 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 chapter thus develops a socio-technical framework for urban inequalities through linking the perspectives to ideas drawn from complexity theory.

2.4 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 contextualise 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.

2.4.1 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 (Campbell and Zellner, 2020). As a scientific paradigm it classifies problems based on their level of complexity and recognises 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 recognises that complex systems by their very nature are difficult to describe (de Roo et al., 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-organisation (Portugali, 2000).

Geographical analysis covers a diverse set of methods, tools, thematic areas, and theories. Importantly geographical analysis is centred on the generation of a diverse body of knowledge associated with the unique characteristics of spatialised data (Singleton and Arribas-Bel, 2019). A number of researchers within geographical analysis recognise 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 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 characterising 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 Figure 2.4. 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 through access and distribution. In this way, urban inequalities emerge as a complex socio-technical phenomenon.

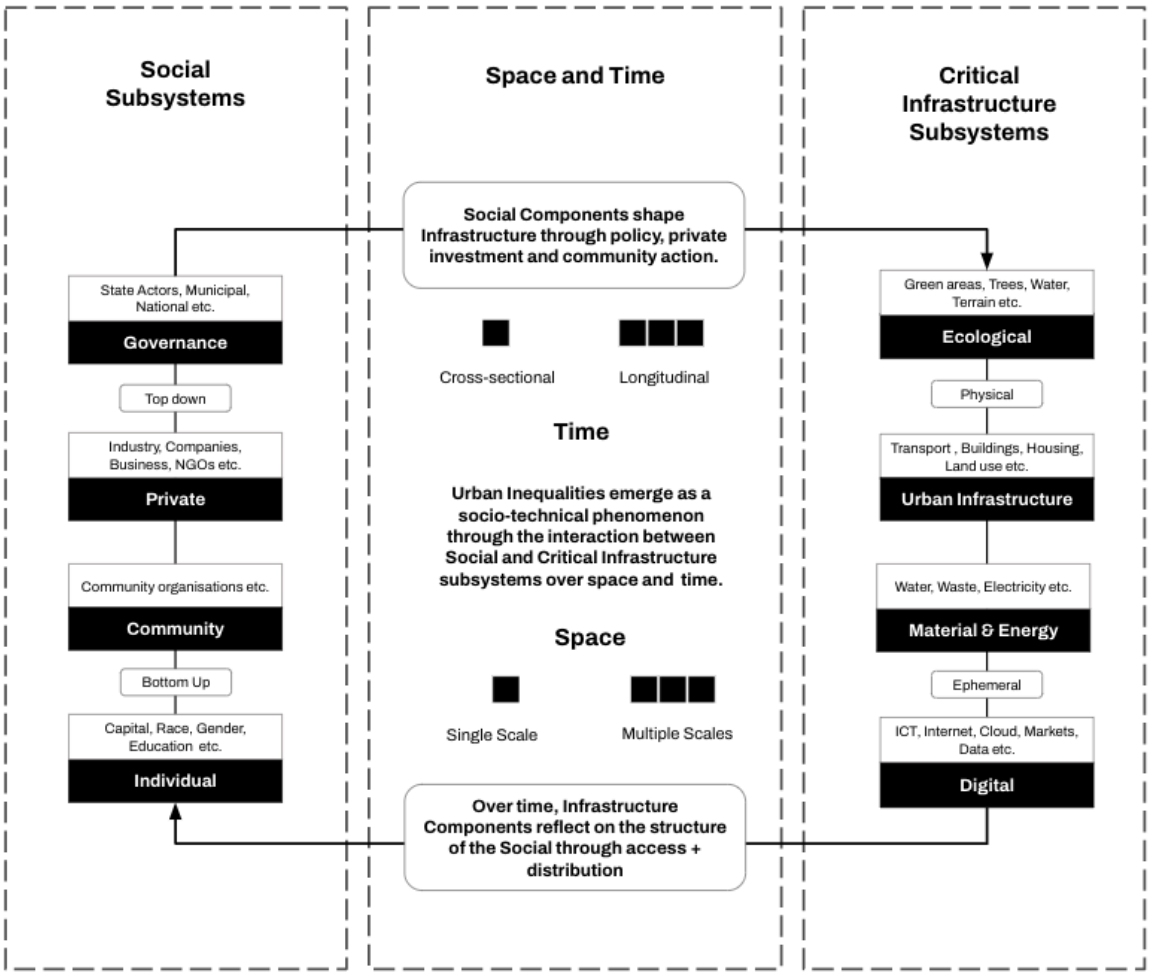


Figure 2.4: A conceptual model of the urban as a complex socio-technical system, framing urban inequalities as an emergent socio-technical phenomenon that develops over space and time.

In unpacking the interactions between the components of each system, it is important to realise that they 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, where systemic inequalities are prevalent in the distribution of amenities (Nicoletti et al., 2023) 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. Urbanisation is an ongoing and dynamic process (Bulkeley and Castán 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 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 2.3, usually focus on the interaction between two or more of the subsystems represented in Figure 2.4. 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. (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 2.4.

2.5 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 four key relational themes and trends. These themes were identified as being important for the understanding of processes that reproduce inequalities over space and time through a collective review of the literature across the identified geospatial research perspectives. They are:

- 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.

2.5.1 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, Singleton 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 (Martínez et al., 2018; Slovic et al., 2019).

2.5.2 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 neighbour-hoods, 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.

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 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 2.4.

2.5.3 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 Inequality Report, 2022). The World Inequality 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) 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) show 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 (SACN, 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 in relation to the management and distribution of infrastructure, such as housing. The importance of local context to national policy design and outcomes is 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).

2.5.4 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 2.4, 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 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 Inequality 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 occurence, 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 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 group-

ings 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).

2.6 Discussion and research agenda

In summary, this article makes three primary contributions:

- Firstly, a multi-disciplinary 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 Figure 2.4.
- 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 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 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 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 2.4, 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, 2013). Feedbacks and non-linearities 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, 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. 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 geospatial 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".

2.7 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.

Housing Inequalities: the space-time geography of housing policies

Housing inequalities are often framed as an outcome of macro-economic structural changes or as a product of local socio-spatial conditions, but the interactions between the two are less understood. As identified in the 2nd Chapter, two of the predominant research lenses for the study of inequalities are *distribution* and *policy and stakeholder* lenses. This chapter integrates these approaches to develop a descriptive methodology to connect the analysis of national housing policy trends in the Netherlands with local socio-spatial trajectories of neighbourhood change using nearly 20 years of historical data across a range of socio-spatial dimensions from the City of Rotterdam. Whilst nationally there has been an increasing policy preference for home ownership associated with a narrative of social upliftment, the spatial-temporal analysis reveals that the wealthiest neighbourhoods have benefitted significantly more from capital gains and increased rates of home ownership over time. Through descriptive analysis, the results highlight the role of divergent neighbourhood characteristics and path dependencies, suggesting that housing policies could benefit from the adoption of a more localised approach. This chapter was originally published in Cities Journal: Nelson, R., Warnier, M., Verma, T., 2024. Housing inequalities: The space-time geography of housing policies. Cities 145, 104727. https://doi.org/10.1016/j.cities.2023.104727

"Housing is a physical requirement. But it is also much more – it is a spiritual need which goes to the root of a dignified and tolerable life."

– Joe Slovo (1994)

3.1 Introduction

According to the World Inequality Report (2021:3), the share of total global wealth owned by the bottom 50% is 2%, contrasted against the top 10% who own 76% of total global wealth. The rise in total private wealth and vast increases in wealth-to-income ratios in the 21st century can largely be attributed to growth in the value of capital gains through housing (Fuller et al., 2020). This is reinforcing a growing divide among those who cannot afford to purchase a home, those who can buy their own home and multiple property owners (Adkins et al., 2020; Mezaroş and Paccoud, 2022).

Housing inequalities are structural in nature in that they reflect persistent disparities in the distribution of housing across population groups (James et al., 2022). They may indicate differences in levels of home ownership (Bonnet et al., 2018; Hochstenbach, 2018; Lowies et al., 2022; Smith et al., 2022), disparities in capital gains over time (Wind and Hedman, 2018; Mayock and Malacrida, 2018) and availability of housing in centrally located and well-connected areas (Martínez et al., 2018; Rokem and Vaughan, 2019). Housing inequalities are rooted in multiple causes. On a structural level they are exacerbated by both high price inflation, periods of economic instability and recession (Forrest, 2021) and can be driven by historical policy processes, such as the discriminatory practice of redlining in the United States which excluded predominantly Black neighbourhoods from accessing loans to purchase homes (Faber, 2021). They are also related to local geographic factors like access to job opportunities and transportation (Martínez et al., 2018) and social disparities in income (Boelhouwer, 2020), race (Sharp and Hall, 2014) and migrant status (Wind and Hedman, 2018; Kolb et al., 2013). Housing wealth accumulation is a cumulative process which happens over both space and time (Fuller et al., 2020; Modai-Snir and van Ham, 2020). What separates housing from other global financial markets is that it is physically embedded within a local context that is shaped by particular demographic, economic and spatial conditions.

Housing inequalities are often conceptualised either as an outcome of macro-economic processes, such as the financialisation of the housing market (Aalbers et al., 2017), or local spatial-temporal conditions through the lens of neighbourhood change, but few studies systematically connect the two. Neighbourhoods are theorised as an important spatial unit in which both decision making from the *bottom-up* (individual and local) and *top-down* (centralised, higher-level authorities) meet (Sampson, 2018). The 'neighbourhood effects' literature suggests that local contexts matter and impact the collective social lives of communities (Suss, 2023:3). Conceptualising policies within a trajectory framework of neighbourhood change has the potential to increase our understanding of how they contribute in shaping present conditions. To gain a multidimensional understanding of the socio-spatial context of neighbourhoods (Patias et al.., 2022), one can use geo-demographic classification, a dimension reducing technique that helps condense large data sets (Voas and Williamson, 2001) and when applied to neighbourhoods enables a multidimensional understanding of their socio-spatial context (Patias et al., 2022). Policy is not independent from geography and in the same way neither can geographical trajectories of neighbourhood change be divorced from institutional changes within the policy landscape.

In this chapter we conduct a comparative trend analysis between institutional changes in housing policy and the geo-demographic classification of trajectories of neighbourhood development employing Rotterdam in the Netherlands, as a case study. We specifically focus on changing distributions in home ownership, capital gains, levels of social housing and income-to-house value ratios. The Netherlands, whilst possessing relatively low income inequality, when internationally compared has one of the highest levels of wealth inequality in the world with the top 10% estimated to own almost 50% of all wealth (World Inequality Database, 2023). The remainder of the structure of this chapter is as follows, Section 3.2 develops a theoretical framework for this study through a review of related literature, Section 3.3 outlines the Methodology, followed by the presentation of the results in Section 3.4, a Discussion of the key findings in Section 3.5 and Conclusion with key contributions and avenues for future research in Section 3.6.

3.2 Housing inequalities

3.2.1 Macro-economic processes

3

Scholarly interest in housing inequalities through macro-economic processes tends to highlight the profound structural changes associated with the deregulation and liberalisation of advanced economy banking systems implemented in the 1980s (Christophers, 2021; Arundel and Ronald, 2020; Byrne, 2020). These changes are linked to significant decreases in public spending through increasing reliance on private companies for the delivery of major infrastructural development and investment (Graham and Marvin, 2001). This was coupled with policy that prioritised home ownership through the deregulation of housing markets and increasing financing of mortgage loans to enable greater access by individuals (Ryan-Collins, 2021:480).

Various authors provide insights into the political motivations associated with these structural reforms. Forrest (2021) determines that these changes were initially politically driven by social, rather than investment considerations. New wealth would be generated through home ownership, creating more egalitarian and socially inclusive societies. Arundel and Ronald (2020) reflect on a political vision across North America, Europe and Australia, which espoused widespread and equitable home ownership in the future, that would lead to a reduction in inequalities and overall improvement in the well being of families and individuals. Ronald et al. (2017) argue that lowering the barriers in accessing home ownership across societies was linked to a wider project of asset-based welfare, that encompassed state supported access to a raft of assets built up at the individual level, offsetting dependency on public funds and infrastructure. State support would be reduced and replaced by the benefits of owning a home. These benefits include drawing on the equity a house provides as collateral for loans or as a financial asset to tap into during retirement (Fuller et al., 2020), increased housing security (Forrest, 2021; Berry et al., 2017) and passing the home on as an item of value to children (Kolb et al., 2013:1010; Ronald and Lennartz; 2018).

Despite evidence proposing that these structural changes were initially part of a wider social project, their long term outcomes have been transformed through the commodification and financialisation of real estate, which has become integral to global financial portfolios and a driver of economic instability and crisis (Fields and Uffer, 2016; Aalbers et al., 2017; Dewilde, 2017; Aalbers et al., 2020). This undermines the capacity of a building to function as a home and an item of security for families and individuals (Forrest and Hirayama, 2018; Ronald and Kadi, 2018). Madden and Marcuse (2016) in their book, *In Defense of Housing*, observe three prominent, interconnected and mutually reinforcing trends of *deregulation, financialisation* and *globalisation* of housing that are reshaping housing systems. The *deregulation* of housing has resulted in the weakening or removal of the regulations, customs, and rules governing residential property (Madden and Marcuse, 2016:37). As an example, the retreat of regulation in New York between 1981 and 2011, resulted in the number of rent-controlled apartments decreasing from more than 285,000 to fewer than 39,000 (Furman Centre for Real Estate and Policy, 2012). According to the organisation Living Rent [14], since 1979 in the UK, 4.5 million council homes have been lost to privatisation and demolition, with many tenants being evicted and effectively zoned out of centrally located areas. *Financialisation* is a generic term to describe the increasing power and prominence of actors and firms that engage in profit accumulation through the servicing and exchanging of money and financial instruments (Madden and Marcuse, 2016:39). As a consequence, Wall Street and other global financial investment markets have become key players in real estate investment[15]. The third trend is the *globalisation* of housing. Real estate may be fixed in place, but it is increasingly dominated by economic networks that are global in scope (Madden and Marcuse , 2016:42). In many ways, the Financial Crisis of 2008, illustrates the profound convergence of these three trends. The deregulation and financialisation of housing through subprime lending of

[14] https://www.livingrent.org
[15] https://www.nytimes.com/2020/03/04/magazine/wall-street-landlords.html

mortgage loans, resulted in mass devaluation of homes which had global reach and caused major economic crisis (Renaud and Kim, 2008).

Home ownership levels across a number of societies, such as Japan, the United Kingdom, the United States and Australasia are declining (Forrest and Hirayama, 2018; Arundel and Ronald, 2020). In the United Kingdom the rise in "buy-to-let landlordism" is documented, leading to the term "generation rent" that represents a group of younger people who are not only more vulnerable to exploitative practices in private renting, but limited in their capacity to acquire their own homes (Ronald and Lennartz, 2018:787). In Sydney, Australia, research suggests that investor landlords are growing with an increasingly financialised mindset (Pawson and Martin, 2020). In Dudeland, Luxembourg, Paccoud (2020) shows how the production of housing is concentrated and controlled by a small group of landlords and property developers. García-Lamarca (2020) illustrates that the private rental sector in Barcelona, Spain is playing an increasing important role. These studies support the notion that a new generation of global institutional investors is emerging, edging out individuals from the market (Smith et al., 2022; Christophers, 2022). Furthermore, weak regulation of tenure rights and rental prices enhance investment opportunities in purchasing homes for rental purposes (Hochstenbach et al., 2020:1626) and in this way no longer prioritise the general interests of urban society, but those of the market, as they seek to enhance private investment (Cassiers and Kesteloot, 2017:1917).

In summary macro-economic perspectives emphasise housing inequalities as an outcome of wider political, institutional, and economic processes. Whilst we do not dispute that these structural processes are integral and supported by evidence across a number of case studies, they tend to overlook the role of local contextual dynamics. Thus in the subsequent section we focus on research that that conceives housing inequalities within a framework of local spatial-temporal processes of neighbourhood change.

3.2.2 Local spatial-temporal processes

It is well established that poverty and inequalities converge in certain neighbourhoods (Delmelle, 2016; Vaughan, 2018). Whilst people may be initially sorted out into neighbourhoods by wider socio-economic processes (Cheshire, 2012), such as through the distribution of affordable housing across different zones (Nieuwenhuis et al., 2020), evidence suggests that the distribution of economic and social opportunities enhances polarisation between neighbourhoods over space and time. Localised opportunities, such as access to affordable and efficient transportation (Power, 2012), educational opportunities (Owens and Candipan, 2019), economic opportunities (Chen et al., 2012), social opportunities (Tóth et al., 2021; Kim et al, 2022), healthcare (Mayaud et al., 2019) and characteristics of the spatial configuration of neighbourhoods such as spatial connectivity (Su et al., 2019; Modai-Snir and van Ham, 2018) may contribute to persistent and increasing inequalities.

The study of neighbourhood change is a well established area of research, but until recently the mapping of neighbourhoods beyond two points in time was limited (Delmelle, 2016:37). The advantage of a longitudinal approach is that it is more likely to shed light on the structural mechanisms which contribute to widening inequalities which may facilitate or negatively impact processes of upward social mobility and socio-spatial polarisation. For example, Mayock and Malacrida (2018:92) study transaction histories for homes between 1990 and 2013 across 9 metropolitan areas in the USA, showing that neighbourhoods occupied by the lowest income families are limited in capital gains. This increases divisions between the housing markets of different neighbourhoods, making it difficult for lower income families to relocate. An analysis of the housing pathways of one Swedish birth cohort (1970–1975), based on population-wide register data (GeoSweden), is used to explain differences in capital gains between different social groups in the period of 1995–2010 (Wind and Hedman, 2018). The results indicate more capital gains for individuals with higher incomes and lower capital gains for migrant populations, suggesting that native swedes are able to use their economic and cultural capital to profit in the housing market.

With recent advancements in the availability of multi-dimensional data sets and increases in computational power, new techniques are being adopted from data science and applied to the study of neighbourhood change. Two particularly promising methods are statistical clustering and sequencing techniques. Statistical clustering, when applied to neighbourhood characteristics, aid in the segmentation of neighbourhoods into a set of discrete categories across multiple spatial and social dimensions (Singleton and Longley, 2009). Sequence analysis, when applied alongside clustering, allows for the mapping of neighbourhood transformations as they change between discrete categories over time (Kang et al., 2020). Instead of measuring numerical changes to specific variables across neighbourhoods, sequence analysis evaluates and compares neighbourhoods as holistic trajectories of urban transformations shedding light on the social and spatial processes which allow neighbourhoods to move through social hierarchies over time.

3.2.3 The interaction between the local and global

Scholarly research from macro-economic perspectives rests in explanatory frameworks for rising housing inequalities within wider political, institutional, and economic structural processes (Aalbers et al., 2017; Smith et al., 2022). Although specific case studies may be employed, local contextual factors are often placed beyond deeper interrogation. Whereas evidence from "neighbourhood-effects" literature shows that despite radical transformations of institutional, economic and political structures over time, uneven development patterns across neighbourhoods can persist (Sampson, 2019).

If we adopt a systemic perspective, housing inequalities can be conceived as a complex real world phenomenon that emerges from the interactions between both the *local* and *global*. Studying complex problems requires moving away from a reductionist mindset that emphasises linear "cause and effect" (de Roo et al., 2020) and incorporating multiple perspectives to develop an appropriate analytical strategy. Thus the purpose of this chapter is to utilise the case study of Rotterdam in the Netherlands to advance our understanding of the systemic nature of housing inequalities by connecting and contextualising institutional structural shifts in macro-economic housing policy with socio-spatial trends in trajectories of neighbourhood development.

3.3 Methodology

In this chapter we propose a comparative trend analysis between changes in housing policy and trajectories of neighbourhood development over time, employing Rotterdam, in the Netherlands as a case study (see Section 3.3.5 for an introduction to the case study). The overarching aim of the comparative trend analysis is to engage with both the wider structural and local contextual factors which drive housing inequalities. This requires the implementation of an interdisciplinary methodology that combines the analysis of macro-economic changes in housing policy with the spatial-temporal analysis of neighbourhood development. We define three stages within our methodological process, refer to Figure 3.5.

- Analysis of historical housing policy phases in the Netherlands
- Analysis of spatial-temporal trends of neighbourhood change in Rotterdam
- A comparative trend analysis

3.3.1 Analysis of historical housing policy phases in the Netherlands

The overarching goal of the historical analysis of housing policy is to to gain insights into the structural landscape of housing inequalities by developing a descriptive understanding of changing policy

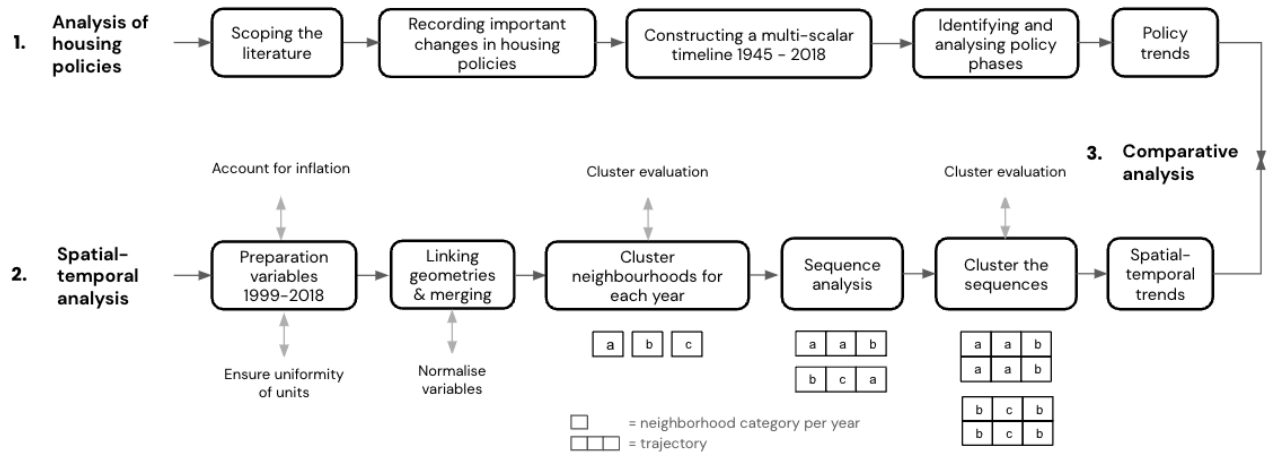


Figure 3.5: A diagrammatic representation of the three stages of the methodological process.

phases between 1945 and 2018 in the Netherlands. This involves scoping literature centred on the analysis of both housing and population changes in the Netherlands to identify, extract and process data that contributes towards an understanding of changing housing policy phases. The following methodological steps are implemented:

Scoping the literature

The primary purpose in scoping literature is to utilise it as a database to extract and analyse important developments related to housing policies in the Netherlands. This includes developments which affect the composition of the population, such as changes in migrant policy, as demographic changes lead to changing demands in housing and as a population grows, more housing is required to meet their needs (Mulder, 2021). The literature is primarily scoped through backwards and forwards snowballing, which is a process of identifying relevant literature through using the reference list and citations in a relevant paper. The starting point for this process is the paper: *The unlikely revival of private renting in Amsterdam: Re-regulating a regulated housing market* by Hochstenbach and Ronald (2020). Each paper is scanned for relevance and this leads to a total of 56 papers.

Recording important changes in housing policies

The literature is scanned to extract important developments related to housing policy, such as the implementation of the *Landlord Levy* placed on Housing Associations in the Netherlands in 2014 (van Gent et al., 2017), the publication of the *Memorandum for Housing in the Nineties* in 1989 (Dieleman and van Kempen, 1994) and the occurrence of significant global events such as the *Global Financial Housing Crisis* of 2008 (Ronald and Dol, 2011). Each development is recorded as an entry in a Spreadsheet with their name, date of occurrence and a brief description.

Constructing a multi-scalar timeline 1945 - 2018

Each entry from the spreadsheet is mapped into a multi-scalar timeline at either Global, National or City scales to develop the housing policy landscape (refer to Figure 3.6) . For example, the Bilateral agreements to attract migrant workers implemented in the 1960s were implemented nationally, whereas, in Rotterdam, where many of the migrants came to work, specific policies focusing on their integration into Dutch society were developed and implemented locally (Dekker and van Breugal in Crul et al., 2019).

Identifying and analysing policy phases

Through an examination of the multi-scalar policy landscape, three overarching phases are identified:

- 1945 - 1989: Highly regulated housing in the Netherlands with an emphasis on public social housing.
- 1989-2008: Significant decrease in regulation with an emphasis on home ownership.
- 2008 - 2018: Increase in regulation with an emphasis on home ownership.

An analysis of the phases is conducted through mapping changing institutional relationships between institutional actors, analysing the defining policy objectives of each phase and the level to which these objectives were achieved. It is important to recognise that public policies are usually generated within networks in which multiple actors are interrelated in a systematic way (Kenis and Schneider, 1991; de Bruijn and ten Heuvelhof, 2018). We conceive each policy phase as a multi-actor process and identify the main institutional actors as those who may influence or be influenced by housing policy as: the Housing Associations, private owners, low income renters, middle income renters, private landlords, State actors and the Bank as a source of financing, refer to Figure 3.7.

3.3.2 Spatial-temporal analysis of neighbourhood change in Rotterdam

The overarching goal is to shed light on the local spatial-temporal mechanisms associated with housing inequalities in Rotterdam. This analysis utilises multi-dimensional data sets composed of social, economic and urban variables at the administrative boundary of the neighbourhood in Rotterdam from 1999, 2001, 2003, 2005, 2007, 2009, 2011, 2013, 2015 and 2018. This methodology broadly draws on the work of Delmelle, (2016), Lee et al. (2017) and Patias et al., (2022) and firstly classifies the neighbourhoods for every year into a set of discrete categories, utilising K-means clustering, yielding a temporal sequence for each neighbourhood of discrete types and then secondly applies sequencing analysis methods to provide insights into these local urban transformations. The spatial-temporal analysis is composed of three phases: *Data preparation of neighbourhood variables, Linking geometries and merging the data sets* and *Trend analysis.*

Data preparation of neighbourhood variables

Each year of the analysis possesses multidimensional *demographic, economic* and *urban* variables at the administrative boundary of the neighbourhood in Rotterdam as defined by the Central Bureau of Statistics (CBS). The majority of the variables are derived from the (CBS) and South Holland Open Data Portal, but for a detailed explanation of each variable, how they are calculated, why they are included and how we address missing data, refer to Section 1.2 of the Supplementary Material (SM). The specific *demographic variables* are the total population, percentage of native and non-native Dutch and different age groups. Specific *economic variables* are mean income, mean house value and percentages of owned and rental units. Specific *urban variables* include the number of residential, non-residential land uses, mean integration and betweenness centralities of the street network and access to metro and tram. The process of data preparation is as follows:

1. *Ensuring uniformity of variable units:* this allows for relative comparison across the years. For example, if in one year the variable is in the form of an absolute number, but in percentages for all other years, the variable is transformed to a percentage. Furthermore, as part of the data cleaning process it is insured that there is uniformity in the way each variable and neighbourhood is named and spelled across the data sets.

2. *Addressing missing data:* ensuring that any missing data was appropriately addressed, refer to the SM for further details.

3. *Adjusting all monetary variables:* the monetary variables are firstly adjusted for inflation according to rates as denoted by the International Monetary Fund to enable comparison across the years. In conducting this process, we find that the monetary variables have increased significantly beyond rates of inflation. Thus to allow for the identification of where relative wealth and poverty have persisted over time, the monetary variables are normalised for each year individually. The normalisation process enables the values to be placed on a scale with a range between 0 and 1. Thus for example, it transforms the highest income values across all years to 1. For a comprehensive description of the normalisation process, refer to Section 1.3 of the SM.

Linking Geometries and merging the data sets

The neighbourhood boundaries remained relatively consistent across the years, but there are slight modifications and thus for ease of comparison all of the data sets are linked by their neighbourhood names with the geometry of the same name from 2018. Once linked to the same geometry, the multiple data sets are merged into one using concatenation in python, resulting in a data set with every neighbourhood (*70 neighbourhoods*) possessing one row of data for each year (*10 years*) and thus a total of 700 individual rows. After the data sets are merged, the variables which had not been normalised previously are normalised in preparation for K-means clustering, refer to Section 1.3 in the SM for more details.

Trend analysis

K-means clustering for each neighbourhood for each year

Once the data are normalised a K-means clustering algorithm is applied to identify distinct typologies for each neighbourhood for every year. K-means clustering is an established unsupervised machine learning technique which enables the identification of categories within a data set in which unlabelled data is fed into the algorithm and partitioned based on the nearest mean (Géron, 2017:8). It assigns the original n objects (700 neighbourhoods) into k clusters and each object is assigned to the cluster whose centre is closest to that object. In this case, K-means clustering is chosen over other clustering algorithms, such as K-medians, as as it is well suited for data which follows normal distributions and has continuous variables, as is the case with this underlying data. The number of clusters, k is predefined and the best k value will lead to the strongest cluster groupings. To determine the optimal k value, the *Silhouette Score* is applied (Rousseeuw, 1987) and in this case *4 clusters* represent the optimal solution, refer to Section 1.4 in the SM for additional information.

Sequence analysis

Sequencing analysis was originally developed to study DNA transformations and subsequently applied to life course analysis (Kang et al., 2020). In the context of this study, it is applied to the neighbourhood categories derived from K-means clustering to identify similar sequence trajectories. The TraMineR package in the R programming language is employed (Gabadinho et al., 2011) to implement the following steps:

1. A neighbourhood's trajectory is referred to as a *sequence state object* and each sequence state object is composed of the grouping of each discrete category it was assigned in chronological order for each year from the K-means clustering process. We thus have 70 sequence state objects.

2. A pairwise dissimilarity matrix between the sequences is calculated utilising the *Dynamic Hamming Distance* method (DHD) (refer to Lesnard, 2010) to understand how one sequence may be

transformed to the other through substitutions. The DHD method is based on the Hamming Distance method, which utilises a constant substitution cost (=1) and an infinitely large cost for insertion or deletion. It differs from the Hamming method in that it accounts for the different timings of each transition between neighbourhood categories by providing different substitutions for each year (Lesnard, 2010).

3. Categories of sequence trajectories are identified through clustering the pairwise dissimilarity matrix to establish groups consisting of similar sequence trajectories. In this case, a Partitioning Around Medoids (PAM) clustering algorithm is applied. PAM is a modification of the traditional K- means and is more appropriate as the dissimilarity matrix is ordinal and not normalised. Various cluster solutions are assessed using *Silhouette Scores* (refer to Section 1.4 in the SM), resulting in a total of 9 distinct classes of trajectories of neighbourhood change.

3.3.3 Comparative trend analysis

The final stage consists of a descriptive comparison between the spatial-temporal trajectories and housing policy trends. To do this comparison neighbourhood variables that can directly be linked to the changing housing policy phases are examined within each category of sequence trajectories. The specific variables are related to:

- home ownership
- social housing
- capital gains
- income to house value ratios

We focus on these variables, as this is data directly related to housing that we have access to. We acknowledge that they may not comprehensively give a complete picture, and other variables, if available, could have been included; nevertheless, in combination, they offer valuable insights. The median value for each variable per year for each sequence trajectory category is plotted across the entire time period and visualised through line graphs. This allows the changing values to be associated descriptively through time to the policy phases.

3.3.4 Data quality issues

The analysis of historical housing policy is able to adopt a much wider timescale, than the spatial-temporal analysis, as the variables included in the neighbourhood data sets are only available from 1999. Further limitations are imposed on the spatial-temporal analysis in relation to the availability of data across all of the years, for example the exact composition of the non-native Dutch population is only available for later years and thus could not be included across the entire time period. Finally, as we rely primarily on secondary data, we acknowledge that there may be bias or inaccuracies in the manner in which the data was collected, by for example labelling someone as non-native Dutch when they may identify as native Dutch.

3.3.5 The case study of Rotterdam in the Netherlands

The Netherlands possesses relatively low income inequality. However, when wealth is taken into account, the country exhibits much higher levels of inequality, especially since the 1980s when it began to rise after a period of significant reduction since the Second World War (Bavel and Frankema, 2017:61).

Rotterdam is the second largest city in the Netherlands and a major logistical hub, possessing the biggest port in Europe. For many decades it has attracted international migrants (Entzinger and Engbersen, 2014). However, Rotterdam has not achieved the global status of a city like Amsterdam.

Whilst "global cities" compete for highly skilled international labour forces, attracting global expats from all with their advanced knowledge-based economies, migration within "secondary cities" is usually based on capital intensive projects which are aimed at reducing production costs (Crul et al., 2018:8). Rotterdam follows this pattern of development: Chinese sailors arrived in the early 20th Century to work on Dutch ships, migrant labourers settled from Morocco and Turkey in the 1960s followed by postcolonial immigrants from Indonesia, Suriname, and the Dutch Caribbean (Entzinger and Engbersen, 2014). As a result, Rotterdam possesses vast economic, social, religious and language differences, with local politics often hinged on issues of multiculturalism and cultural assimilation (Crul et al., 2018:8). Previous research shows that Rotterdam has persistently remained divided along class lines of rich and poor (Musterd et al., 2020). In addition, there is a lack of literature in"secondary" cities and this case study reflects on housing inequalities in such an urban space.

3.4 Results

3.4.1 The analysis of historical housing policy phases

The intention of the housing policy analysis is to engage with changing phases in housing policy over time to shed light on the wider macro-economic and structural processes which influence housing inequalities. The policy landscape is mapped according to international, national and local levels between the periods of 1945 and 2018 (refer to Figure 3.6). It is important to ascertain the differences in approach between city and national level policies (Scholten, 2016) as local policies may be driven by different models to national policies (Crul and Schneider, 2010). Figure 3.6 reveals that housing policies tend to be implemented at a national level and strongly influenced by global macro-economic attitudes. In closely examining housing policies within the context of this wider policy landscape, three predominant phases are inductively identified. These phases are:

- 1945 - 1989: Highly regulated housing in the Netherlands with an emphasis on public social housing.
- 1989 - 2008: Significant decrease in regulation with an emphasis on home ownership.
- 2008 - 2018: Increase in regulation with an emphasis on home ownership.

The first phase is between 1945 and 1989 and is characterised by a high degree of government regulation and intervention. This phase directly links to ideals espoused by the Welfare State which was the dominant mode of governance across Europe at the time. This era is referred to as the "golden age" for social housing in Europe, output levels were at the highest rate they had ever been and the mass model dominated (Malpass, 2008:17). In the Netherlands, the private and public housing sectors were clearly delineated from each other, refer to Diagram A in Figure 3.7. The private housing sector was constituted by owner occupied and privately rented homes, financed either through personal wealth or loans and the public sector was operated by non-profit Housing Associations (HA). The HA were established initially in 1901 through the Housing Act [16], and received subsidies and loans directly from the State. Following World War 2 they were subject to an increasing number of government regulations and controls, such as the supervision of building requirements and construction, decisions on the choice of architect and the tendering of contracts (Beekers, 2012; Aalbers et al., 2017:7). During this phase, Rotterdam experienced a relative period of political stability, as local political parties were united in rebuilding the city, which had been flattened in World War II (van Ostaaijen in Crul et al., 2019). The population composition in Rotterdam would begin to change in the 1960s as a result of the new bilateral trade agreements between the Netherlands and Turkey and Morocco, leading to Rotterdam being the first city in the Netherlands to implement policies centred on social integration (Dekker and van Breugal in Crul et al., 2019).

[16]https://www.eerstekamer.nl/plenair/20210706/talsma

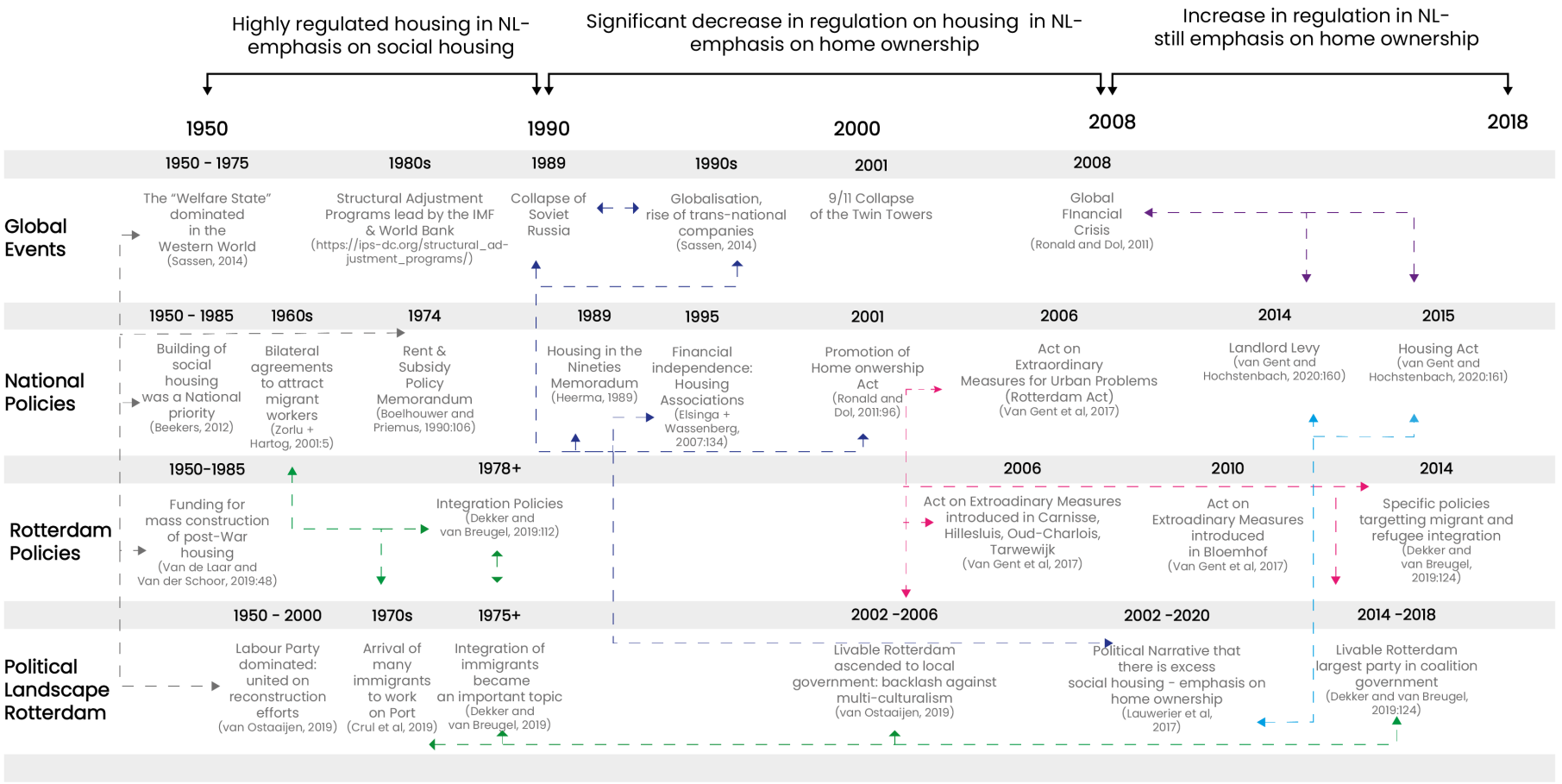


Figure 3.6: Mapping of the historical housing policy landscape at local, national and international levels, through which we identify the three housing policy phases.

The defining policy objectives of this phase were centred on solving the acute housing shortage directly after World War II, which deemed the high level of government intervention necessary to meet the needs of both middle and lower class population groups (Boelhouwer and Priemus, 2014:223). After the initial crisis subsided, the housing agenda was later tied into a cohesive policy of urban renewal (Musterd and Ostendorf, 2021). In impoverished neighbourhoods with bad housing conditions, urban renewal concentrated on building new dwellings and upgrading existing ones, intended as a measure to improve the position of financially less well off residents (Vermeijden, 2001:218). The HA received government support to build an average of twenty thousand houses every year nationally and their property doubled in the 1950s to four hundred thousand homes with more than a hundred institutions each managing more than a thousand, sometimes even thousands, of homes (Beekers, 2012:195). The public sector's share of the total housing stock in the Netherlands grew from 12 % in 1945 to 41 % in 1975 and 44 % by the early 1990s (Boelhouwer and Priemus, 2014:223).

The second phase is between 1989 and 2008 and is characterised by a significant decrease in regulation with an emphasis on home ownership. This results in the financial and administrative independence of the HA from the central government and echoes international trends towards the deregulation and privatisation of public housing that began in the 1980s (Forrest, 2022:3). In Diagram B in Figure 3.7, we observe the rising prominence of central banks, with the HA directly receiving funding from them and the State serving only as a third party guarantor (Ronald and Dol, 2011:100). The key differences between renting from a HA versus other private landlords, is that most of the rents are subsidised, regulated and only available to lower and middle income residents. In Rotterdam local politics entered a more divisive phase, especially during the period of 2001-2006, in which the Livable Rotterdam party rose to power. Their election campaign was centred on Islam, safety and immigration and they were also key in the implementation of the *Act on Extraordinary Measures for Urban Problems*, also known as the *Rotterdam Law*, which was approved by national government (van Gent et al., 2018). The *Rotterdam Law* allows the municipality to restrict citizens under a certain income limit from moving into specific neighbourhoods, all of which are located in the South of Rotterdam. Whilst the *Rotterdam Law* does not specifically target non-native Dutch populations, low income earners are highly correlated with non-native Dutch residents. It is important to acknowledge this policy in the context of housing, as it restricts certain citizens from living in specific neighbourhoods and thus affects the housing they are able to access.

The defining national policy objectives of this era were focused on releasing the heavy burden that public housing imposed on the State through promoting market efficiency of the housing sector through deregulation, decentralisation and self-sufficiency (Boelhouwer and Priemus, 2014; Ronald and Dol, 2011). This shift in institutional goals represents an intention to stimulate increased levels of home ownership. The HA would be able to sell off parts of their existing stock to tenants, alongside other measures such as home ownership schemes offering low-income families home-purchase subsidies (Ronald and Dol, 2011:96). Statistical evidence shows that after 1992, the share of stock owned by HA declined and reached a share of approximately 31% in 2012, previously being 44% in 1990, in line the policy objectives (Boelhouwer and Priemus, 2014:223). However, an unforeseen outcome was the global boom in housing prices is that it allowed the the HA to reap sizable financial benefits and as a consequence become very wealthy, allowing them to use their real estate – often worth billions of euros – as collateral for new loans and investments (Aalbers et al., 2017:10). Many associations started developing housing for profit and several of them adopted more complex financial techniques, such as lending money to other associations, borrowing on global capital markets and buying derivatives (Aalbers et al., 2017:10). Furthermore, the transferal of stock from housing associations to tenants did not take place at the rate envisioned, due to an unwillingness by the HA to sell off stock and prices often being too high for the average social housing tenant to afford (Ronald and Dol, 2011:95).

The third phase is between 2008-2018, and represents an increase in regulation with a continued emphasis on home ownership. The global financial crisis in 2008 directly shapes this phase, revealing the financial mismanagement of many of the HA and led to the bailing out of one of the largest Housing Associations, Vestia, costing the State more than 2 billion Euros (Boelhouwer and Priemus, 2014:229). Two major reforms were introduced, the first being that the Dutch parliament required the HA to explicitly provide housing to lower income target groups only, restricting it from middle income earners (van Gent and Hochstenbach, 2020:161). Secondly, a new tax targeting the rental income of the HA is introduced in 2014 (van Gent and Hochstenbach, 2020:160), to claw back the extra rental income HA could collect by introducing new rent increases for households with a higher income in the social rented sector. Refer to Diagram C in Figure 3.7 for a diagrammatic representation of changing relationships.

This phase is imbued with a strong motivation to reduce the power of the housing associations, through limiting their target group and ensuring any extra rental income which could be used to reinvest and increase stock is taxed (Aalbers et al., 2020:548). In recent years there is growing media attention around rising rents and national housing shortages, although a narrative that excess social housing both nationally and locally in Rotterdam continues to persist (van Gent and Hochstenbach, 2020:162; Lauwerier et al., 2017). In the past, HA have been central in anti-cyclical responses to market downturns. However, while they still control approximately 31% of housing stock, they have been constrained in their abilities to offset falling private supply and demand with increased rental housing development (Ronald and Dol, 2011:108).

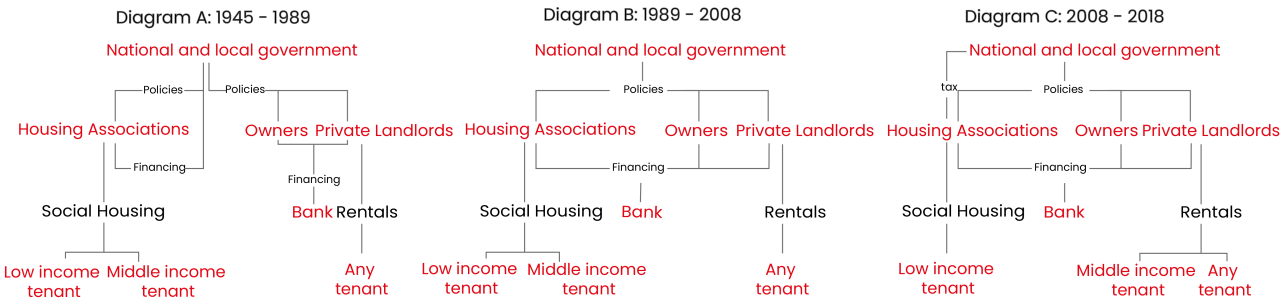


Figure 3.7: Diagrammatic visualisation of changing institutional relationships across the phases between multiple actors involved in the formation of housing policies.

3.4.2 Spatial-temporal analysis of neighbourhood trajectories in Rotterdam

In this section the case study of Rotterdam is examined to understand how housing inequalities manifest locally. Due to data availability, the spatial-temporal analysis commences at the beginning of the second phase identified in the analysis of housing policy in 1999, following the privatisation of the Housing Associations in 1995.

The neighbourhood data sets are merged and clustered, leading to the multi-dimensional categorisation of each neighbourhood for every year of data. A four category solution is found to be optimal, based on the *Silhouette Score*. Each cluster is described below, refer to Figures 3.8 and 3.9 for visual depictions of the cluster solutions. Figure 3.8 provides a brief summary of the defining characteristic of each cluster, whilst Figure 3.9 shows each neighbourhood within their respective category through maps relating to the years 1999, 2005, 2011 and 2018.

Cluster 1 - Affluent Native Dutch:
Cluster 1 is characterised by a high percentage of affluent native Dutch families. Out of all four categories, this category possesses the highest levels of home ownership, mean incomes and real estate

of the greatest estimated value. These neighbourhoods possess reasonable access to the tram system and the highest mean betweenness centrality, indicating that they are well connected to roads with high through movement potential and thus able to access routes which can quickly get them into the city.

Cluster 2 - Native Dutch:
Cluster 2 is characterised by a high percentage of native Dutch population, with a significant percentage of residents above 65 years of age. These neighbourhoods possess larger populations than the *Affluent Native Dutch* neighbourhoods and lower average incomes, reduced levels of home ownership and weak access to both the tram and metro underground train system.

Cluster 3 - Diverse Young Professional:
Cluster 3 neighbourhoods are the most demographically diverse and possess an almost equal combination of both non-native and native Dutch populations, dominated by the age groups between 25 and 44 years old. More residents reside in rental homes than owned properties, although they do have higher levels of income than the *Native Dutch* neighbourhoods, the income levels are still significantly less than the *Affluent Native Dutch* neighbourhoods. They are spatially integrated with the highest access to tram, metro and non-residential land-use.

Cluster 4 - Non-native Dutch:
Cluster 4 neighbourhoods have the highest proportion of non-native Dutch families. Out of all the categories, these neighbourhoods have the lowest mean incomes, mean house values and the majority of their residents reside in rental properties. They have decent access to the tram system and non-residential amenities, but weak access to the metro.

A sequencing analysis is conducted utilising the designated cluster categories for each neighbourhood for every year to construct neighbourhood trajectories over time. This allows insights to be gained into whether a neighbourhood has remained stable within a particular category or transitioned between different categories over time. Subsequently, the sequence trajectories are clustered, as shown in Figure 3.10, to identify categories of similar sequences. For example, *Stable native Dutch* to *Non-native Dutch* contains neighbourhoods which transformed from being originally *Native Dutch* in categorisation to predominantly *Non-native Dutch* over this period of time.

In examining the transition rates between the categories, two significant findings become clear. Firstly, they indicate polarisation between *Affluent Native Dutch* and *Non-native Dutch* neighbourhoods. Once a neighbourhood is classified as predominantly *Non-native Dutch* or predominantly *Affluent Native Dutch*, the neighbourhood is unlikely to transition from that category and usually remains stable within the category. The neighbourhoods which have been subject to the *Rotterdam Law* have remained within the *Non-native Dutch* category, which is relatively the poorest neighbourhood type, therefore indicating that the policy appears to have had little to no effect in uplifting the socio-economic statuses of these neighbourhoods. Secondly, according to the analysis, either *Diverse Young Professional* Neighbourhoods or *Native Dutch* neighbourhoods may have transitioned to *Non-native Dutch* Neighbourhoods, with only *Native Dutch* neighbourhoods transitioning to the *Affluent Native Dutch* category. Thus the category which has been transitioned to the most is the *Non-native Dutch* categorisation which possess the lowest income levels, indicating that trends of downward neighbourhood social mobility were more likely than upward neighbourhood social mobility.

3.4.3 Relating the spatial-temporal trends to the housing policy phases

To relate the neighbourhood trajectories to the housing policy phases, we focus on how the variables, which are specifically centred on housing, have changed over time within each of the sequence trajectories. The specific variables that are examined are: percentage of homeowners, percentage of social housing units, house prices and ratio of mean income to house prices. Refer to Figure 3.11, for a visual representation of the distribution of these variables across the sequence trajectory categories.

Cluster 1:
Affluent Native Dutch families

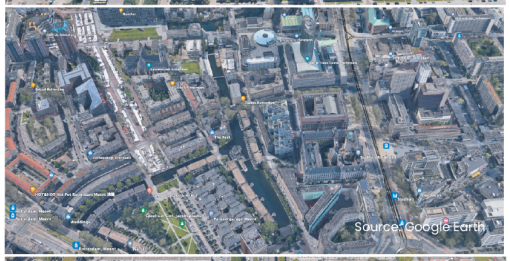
- Predominantly native Dutch families.
- Highest levels of home ownership, income and housing values.
- Reasonable access to the tram system and well connected to roads that have high through movement potential - thus can easily access city.

Cluster 2:
Native Dutch

- High percentage native Dutch population, significant percentage elderly.
- Lower mean incomes, reduced home ownership and real estate values.
- Weak access to both the tram and metro.

Cluster 3:
Diverse young professionals

- Almost equal combination of non-native and native Dutch populations.
- More rental homes than owned homes, but higher levels of ownerships & income than in Cluster 2 neighbourhoods, still significantly less than Cluster 1.
- Spatially integrated with highest access to tram, metro and non-residential land use.



Cluster 4:
Non-native Dutch

- Dominated by non-native Dutch families.
- Lowest average incomes, house values and highest percentage of rentals.
- Spatially integrated with decent access to tram and non-residential amenities, but weak access to the metro.

Figure 3.8: Summaries of the characteristics of each of the 4 neighbourhood categories identified through K-means clustering.

Figure 3.9: These maps of Rotterdam's neighbourhoods, show them classified in their different categories in 1999, 2005, 2011 and 2018.

Figure 3.10: Neighbourhood Sequence Trajectories: The nine categories of sequence trajectories highlighting changes in socioa-spatial aspects of neighbourhoods. The 70 neighboUrhoods of Rotterdam have been classified among 4 categories of affluent native Dutch families, native Dutch, diverse young professionals and non-native Dutch. The sequences of trajectories of these neighbourhoods are then clustered according to trajectories of change, resulting in 9 variations.

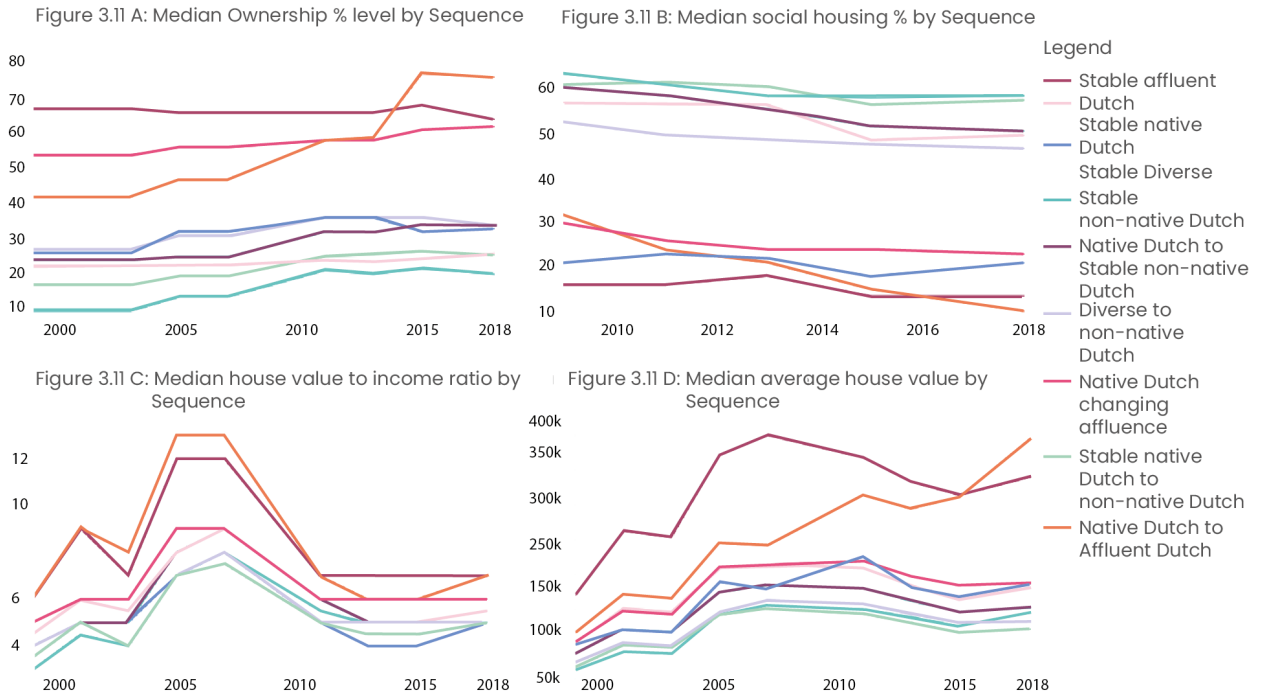


Figure 3.11: These four graphs depict the changing median distributions of variables related to housing across the neighbourhood trajectories from 1999 to 2018.

Whilst the percentage of homeowners across all the neighbourhood trajectories has increased, the trajectory of neighbourhoods that has increased home ownership rates to the largest extent is the *Native Dutch to Affluent Native Dutch* trajectory category (see Figure 3.11 A). Furthermore, the *Stable affluent native Dutch* neighbourhoods have consistently significantly higher percentages of home ownership rates than the other trajectories. These results suggest an imbalance, and that home ownership levels have not risen to the extent to which one would expect considering the significant emphasis on home ownership through national policy.

Whilst levels of social housing are not included directly in the analysis, as this variable was unavailable for earlier years, data exists from 2009-2018. When linking the categories of trajectories to levels of social housing across this period, we observe that social housing has reduced across the entire city, in line with the goals of National Housing Policy trends. However, the neighbourhoods with higher levels of non-native Dutch and poorer residents have consistently the highest levels of social housing, suggesting that the location of social housing probably has a role in determining where poorer and non-native Dutch families reside in Rotterdam (see Figure 3.11 B). Whilst it is difficult to know for certain, due to constraints on the data, it suggests that inter-generational, low income families rely on social housing, probably reinforced by the growing divide between the regulated prices of social housing and renting in the free market (van Gent and Hochstenbach, 2020).

In examining the real value of homes, we observe that the value of housing peaked across the trajectories between 2006 and 2010 and subsequently dropped, revealing the local implications of the global financial crisis (see Figure 3.11 D). Despite the 2008 financial crisis, the real value of housing has effectively doubled across all neighbourhood trajectories from 1999 to 2018. This is indicative of vast capital gains for home owners - especially in wealthier neighbourhoods, which have had relatively the largest increases. This also confirms the incredible gains in wealth of the Housing Associations (Aalbers et al., 2017). The neighbourhood trajectory which has relatively the greatest capital gains, is the *Native Dutch to Affluent Native Dutch* category. Aligning with the work of others (Coul-

ter et al., 2015; Hochstenbach, 2018), these results firstly emphasise the increased real cost for new homeowners to enter the market and secondly the incredible gains in wealth that homeowners have experienced over time. Motivations for deregulating the housing market in the Netherlands were embedded in increasing access to home ownership in the 1990s, but the real price of housing has soared and inadvertently it has become more expensive to enter the housing market than before in Rotterdam.

When examining the ratio of income-to-house prices, (house price divided by income), the effect of the global financial crisis can also be observed, with these ratios peaking around 2008 and dropping after across the trajectories (see Figure 3.11 C). Despite these vast changes in global structural processes, the largest ratios are consistently in the wealthier neighbourhoods. This suggests that the wealthy not only have the highest incomes, but have been able to invest much more and thus have been in a position to benefit the most or have benefited the most from rising housing prices. The 1989 document government memorandum, 'Housing in the 1990s', (Heerma, 1989), emphasises the rediscovery of the market and these results suggest that the wealthy have benefited the most from the "commodification" (Ronald and Dol, 2011) or "hyper-commodification" (Madden and Marcuse, 2016) of real estate both in increasing home ownership levels and capital gains.

3.5 Discussion

In this chapter we develop as approach to relate institutional changes in housing policy with the spatial-temporal analysis of neighbourhood change, utilising Rotterdam in the Netherlands as a case study. This discussion is centred on how the results may enhance our understanding of the structural nature of housing inequalities.

3.5.1 Housing inequalities are multi-scalar

All housing possesses a local context, but processes of globalisation and shifts in macro-economic policy in the 1980s, have led to policies that emphasise the free market, privatisation and deregulation which in turn makes it difficult to separate real estate from global financial markets (Forrest, 2021; Modai-Snir and van Ham, 2020). The results of the policy analysis underline significant institutional changes, successes and failings within national housing policy in the Netherlands between 1950 and 2020. In contrast, the spatial-temporal analysis employs multidimensional empirical data at the neighbourhood scale to provide insights into local spatial-temporal trends between 1999 and 2018. Whilst the analysis of housing policy, in combination with national level statistics conveys a narrative of increased emphasis on home ownership, the spatial-temporal analysis reveals that despite these structural shifts in policy, persistent housing inequalities exist in certain neighbourhoods in Rotterdam. Especially when comparing *Non-native Dutch* and *Affluent native Dutch neighbourhoods* in relation to levels of home ownership and capital gains. In general, the affluent neighbourhoods have had the most capital gains and increased levels of home ownership across time. In this way, the outcomes of changes in macro-economic housing policy have not been uniform (or equitably distributed) across populations and space. It provides critical information on representation, suggesting "where" and "who" may have benefited from increased emphasis on the market to meet the housing needs of the Dutch population This analysis shows that there are different housing needs, for different kinds of communities, and therefore suggests that blanket policy interventions applied nationally are unlikely to equally or equitably meet the needs of diverse populations.

3.5.2 Spatial polarisation and concentrations of disadvantage

The analysis of housing policy shows that housing marketisation has been central to housing policy in the Netherlands since the 1990s. The spatial-temporal analysis reveals that the real house prices in Rotterdam have more than doubled across all neighbourhoods over the twenty year period and the greatest capital gains are in the wealthiest areas, which are predominantly *Affluent Native Dutch* or

have become predominantly *Affluent Native Dutch* over time. Other studies have shown that there is a tendency for market driven housing economies to result in increased spatial polarisation (van Gent and Musterd, 2016; van Gent and Hochstenbach, 2020) and this study provides further evidence of this trend.

Such dramatic increases in housing prices make it challenging for first time buyers, whether of a younger generation or recent immigrants, to enter the market. The persistence of low ownership levels in *Non-native Dutch* neighbourhoods speaks to the work of Hochstenbach et al., (2020) who emphasises that inter-generational wealth plays a role in owning a home in the Netherlands. Over time, the number of predominantly *Non-native Dutch* neighbourhoods has increased in the South of Rotterdam below the Nieuwe Maas River, contrasted against a persistent agglomeration of *Affluent native Dutch* neighbourhoods in the far North above the main ring road, refer to Figure 3.9. This suggests that the river and ring road serve as spatial boundaries, which are being reinforced by vastly different housing prices and tenure options, highlighting the concentration of housing wealth and inequalities in space. Furthermore, the neighbourhoods which are subject to the *Rotterdam Law* have persistently remained in the *Non-native Dutch* category, with many of the adjacent neighbourhoods also transitioning to *Non-native Dutch* dominated over time, bringing into question the efficacy of the continued implementation of this regulation.

The *Diverse young professional* category is the most socially inclusive category based on demographic mixing, possessing almost equal numbers of native Dutch and non-native Dutch populations. In examining other characteristics associated with this category, they have the highest access to tram, metro and non-residential amenities. This suggests that the availability of a wide range of transport options and non-residential amenities has a relationship with demographically socially inclusive neighbourhoods in Rotterdam and may be able to counteract some of the negative effects of spatial polarisation through market differentiation.

3.5.3 Spatial-temporal analysis and policy making

The analysis of historical housing policy provides insights into changing institutional relationships and Figure 3.7 illustrates how international banking has become increasingly integral to the financing of housing over time. It also emphasises how regulation has increased emphasis on the private housing sector, through restricting social housing to lower income tenants and deregulating the market to allow for international investment. This induces more demand as middle income tenants shift towards renting from private landlords and homes are purchased for investment (Wind et al., 2020; Ronald and Kadi, 2018). It is important to reflect on more recent policy changes that were not included in the historical analysis. The landlord levy which was placed on HA in 2014 has subsequently been abolished, releasing them of 1,7 Billion Euros which they can use to reinvest in more housing stock (Housing in Europe, 2023). Commitments have also been made to ensure that across municipalities there is 30% social housing stock available. This indicates a recognition of the importance of availability of housing for low income tenants, although middle income tenants still rely fully on the free market and will continue to experience rising rents, which remain largely unregulated.

In contrast to the analysis of historical housing policy phases, the spatial-temporal analysis provides empirical insights into social mobility in Rotterdam and distributions of home ownership and capital gains. The analysis suggests that if a neighbourhood had transitioned to a different category, it would have most likely transitioned to a neighbourhood category dominated by low income and non-native Dutch residents. Comparatively these are the poorest neighbourhoods with the highest levels of rental units and possess homes of the least value, which highlights the persistent lack of social mobility for non-native Dutch population groups. The analysis suggests that housing policies have not taken into account specific socio-spatial conditions and that if the right structural conditions are to be created to allow for upward social mobility.

3.6 Conclusion

Empirical research through spatial-temporal analysis and the analysis of policy are often seen as different worlds. For the purpose of studying and addressing complex problems, such as housing inequalities, there is value in increasing engagement between the two. In line with thinking proposed by Kandt and Batty (2021:7) urban analytics rarely provides direct answers to urban policy problems; however it can be used as exploratory material for the development of new hypotheses and could be a powerful resource in developing evidence which can support the policy making process.

To understand housing inequalities at the urban scale requires engaging with both policy and spatial-temporal analysis, and examining their relationship. The analysis of policy provides insights into the dynamics of high level institutional relationships and the wider policy landscape in which changes happen. Whereas, the spatial-temporal analysis offers opportunity to critically reflect on the effectiveness of policies and *who* and *where* may have benefited the most in accessing home ownership and increasing capital gains. In summary, this analysis has lead to these new findings:

- The spatial-temporal analysis reveals that despite large, structural shifts in policy, such as those that came about from the Global Financial crisis of 2008, failed to disrupt relative hierarchies between neighbourhoods, with the wealthiest neighbourhoods remaining wealthy with consistently greater capital gains and levels of home ownership over time. This brings into question the ability for structural shifts in policy, despite being substantial in size, to significantly disrupt local neighbourhood hierarchies.

- Within Rotterdam, the river and ring road serve as spatial boundaries, which are being reinforced by vastly different housing prices and tenure options. This indicates that the spatial concentration of housing inequalities has a relationship the local spatial configuration of the city.

- Neighbourhoods which are subject to the *Rotterdam Law* have persistently remained in the Non-native Dutch category, with many of the adjacent neighbourhoods also transitioning to majority Non-native Dutch over time. This not only undermines the reasoning for the continued implementation of this particular policy, but more widely suggests that social policies based on exclusion are not appropriate for regulating local neighbourhood development.

- If a neighbourhood had transitioned to a different category, it would have most likely transitioned to a neighbourhood category of predominantly low income and non-native Dutch residents which relatively are the poorest neighbourhoods with the highest levels of rental units and possess homes of the least value. This suggests that the increased marketisation and privatisation of housing, which follows international trends towards housing, has for the most part only benefited neighbourhoods in Rotterdam which were wealthy to begin with.

Housing inequalities are complex and this study has shown that they are reproduced by many interconnected, multi-scalar factors. Future analysis needs to continue to explore the implications of both the *size* and *scale* at which policy interventions are implemented. The continuation of the development of methods to relate the analysis of past, current and future policy with spatial-temporal analysis has the potential to enhance our understanding of both the "bottom-up" effects and "top-down" structures which reproduce complex urban problems, such as housing inequalities.

Ethically Informed Urban Planning: developing metrics for distributive spatial justice

The previous chapter focused on housing inequalities through both *distribution* and *stakeholder and policy* lenses. Chapter 4 focuses on *accessibility* and *distribution* lenses, as identified in the 2nd Chapter, to examine the distribution of accessibility to places of employment through transport. Studies in urban accessibility have advanced our understanding of social and spatial inequalities in the distribution of urban resources in cities worldwide. In response, prominent discourse is shifting to embed justice in urban planning. In this chapter I present the Mapping Accessibility for Ethically Informed Urban Planning (MAP) framework. Map operationalises three metrics of distributive spatial justice based on Equality, Utilitarianism and Rawls' Egalitarian principles to compare the implications of choosing different values of justice to evaluate neighbourhood accessibility. MAP is applied to three diverse cities located in the Netherlands, Mexico and South Africa, modelling each city as an urban network model, integrating public transportation, land use, and street networks. A shortened version of this paper won an award for the best paper in spatial analysis from the Centre for Advanced Spatial Analysis (CASA), University College London, at the annual GISRUK Conference 2024. A preprint of the paper can be found here: Nelson, R., Warnier, M., Verma, T., 2025. Ethically informed urban planning: measuring distributive spatial justice for neighbourhood accessibility. https://doi.org/10.21203/rs.3.rs-4293613/v2 .

"What is a just society? Indeed, in most theories of justice in contemporary political philosophy, that question is taken to be central."

– Amartya Sen (2006)

4.1 Introduction

Over the last fifty years, a profound shift in global urban development has seen the majority of the world's population move from rural to urban areas, with most new urban growth concentrated in global majority countries (Parnell et al., 2009). Due to rapid urbanisation, alongside other notable factors such as decreases in public wealth (Chancel et al., 2022:76), local and national governments are struggling to meet rising demands for essential infrastructure. Advancements in the interdisciplinary realm of urban sciences have repeatedly highlighted the unequal distribution of benefits and burdens of infrastructure provision across urban regions, such as access to public transportation (Luo and Zhao, 2021), environmental quality (Jünger, 2022), heat islands (Pappalardo et al., 2023), and healthcare services (Pereira et al., 2021). As a result, it is well established that there are always inequalities in accessibility due to inherent constraints of urban growth, investment, and the varying needs of diverse populations across cities (Golub and Martens, 2014). However, moving towards the UN Sustainable Development Goals (particularly Goal 10 and 11) requires focusing on the fairness of urban resource distribution and associated impacts on different groups of people, directly linking to ideas embedded within spatial justice (Rocco et al., 2022; Soja, 2010).

Theoretical advancements have given rise to new conceptual frameworks which link theories of justice from moral and political theory with transportation (Van Wee and Geurs, 2011; Martens et al., 2012, Pereira et al., 2017), urban planning (Fainstein and DeFilipp, 2016), and geography (Harvey 2008; Soja, 2010). These advancements emphasise the spatial component of social justice and provide conceptual clarity on how different ethical frameworks, when applied to accessibility, may lead to competing values and outcomes. Nevertheless, many studies that practically develop quantitative metrics of equity for accessibility analyses lack a clear ethical framework (i.e. Chan et al., 2023) or focus solely on one ethical perspective (i.e. Azmoodeh et al., 2023). Furthermore, as the majority of accessibility indicators have been applied within transportation research (Van Wee and Mouter, 2021), there tends to be an emphasis on the performance of transportation networks, whilst other vital factors relating to local socio-spatial characteristics may be overlooked (Fol and Gallez, 2014).

The methodological innovation presented here aims to bring conceptual clarity to planning decisions by developing different spatial justice metrics for neighbourhood accessibility grounded in varying ethical perspectives within a single comparative framework. We refer to this framework, as the Mapping Accessibility for Ethically Informed Urban Planning (MAP) framework. MAP, firstly quantifies existing neighbourhood accessibility levels. This is followed by applying three alternative metrics of spatial justice, which operationalise Egalitarian, Rawlsian and Utilitarian ethical principles, to reimagine what distributions of access would ideally be. Finally, the gap between existing and ideal neighbourhood accessibility levels is calculated to understand which neighbourhoods currently meet the requirement for justice and which do not. The three theories of justice employed within MAP are three of the most applied theories to transport accessibility and could be expanded to include others, such as sufficientarianism. The aim is not to prioritise a singular theory of justice, but to allow for multiple to be compared within a singular framework for debate by stakeholders and citizens.

We embrace a graph network methodology drawn from discrete mathematics (Boeing, 2020). In this approach, the city is conceptualised and modeled as a large graph crucially linking land use, demographic data, transportation and road networks. We apply the method to the diverse case studies of the Metropolitan area of Monterrey in Mexico, the Metropolitan area of Cape Town in South Africa and the polycentric region of the Hague and Rotterdam in the Netherlands to examine neighbourhood accessibility to places of employment. For further reasoning behind the criteria for this selection, refer to Section 4.3. Placing different cities into comparative juxtapositions highlights the shared universal and diverse contextual factors that give rise to spatial justice as a phenomenon and contributes towards a more inclusive agenda for advancing urban science and theory, as called upon by Jacobs (2012), Robinson (2016), Parnell and Pieterse, (2016) and others.

The remainder of the structure of this chapter is as follows: we begin with a review of related literature, which enables us to develop an overarching framework in Section 4.2. Section 4.3 introduces the three case studies, followed by Section 4.4, containing the Methodology, which comprises a 3-stage process. This is followed by a summary of the Results (Section 4.5), Discussion (Section 4.6) and Conclusion (Section 4.7), which summarises the main contribution and contains reflections on the limitations and agenda for future research.

4.2 Developing a framework for Spatial Justice metrics for neighbourhood accessibility

4.2.1 Spatial Justice within urban theory

Initial concerns for spatial justice can be traced back to the early writings of the social geographer David Harvey and the French philosopher Henri Lefebvre. Lefebvre (1968) was one of the first thinkers to conceptualise space as a social product that reflects the justices and injustices which exist within society. From this premise, he advocated that all citizens have a moral right to participate in and shape their urban environment. Harvey (1973) in his seminal work, *Social Justice and the City* reinforces this idea by exploring how the spatial form of cities also shapes justice and injustices within society through the distribution of benefits (resources) and allocation of burdens across populations. More recently, Soja (2010), in his book *Seeking Spatial Justice* through a plethora of contemporary examples, illustrates how social justice cannot be separated from the urban condition.

Spatial Justice can broadly be understood as a moral and political ideal within urban theory that relates to how resources and infrastructure are distributed in space (*distributive justice*), the fairness of processes and procedures of decision-making within cities (*procedural justice*) and the rights of citizens to participate in urban life (Harvey, 2003; Pereira et al., 2017). In this chapter, we focus on distributive spatial justice. Scholars concerned with distributive spatial justice are increasingly drawing on different ethical theories to enhance our understanding of fairness within urban resource allocation. Different ethical theories offer varying conceptualisations of *fairness* and have implications for urban resource distribution. A Utilitarian perspective on ethics states that the right action is the action that is expected to produce maximum pleasure or benefits (Bentham, 1907). However, it is not only the intensity of benefits that counts but also the size of the group that benefits (Sandel, 2010). In the context of city planning, this may lead to decision-making which prioritises the majority, even if that's at the cost of a minority losing out. In contrast, Egalitarian theories are underpinned by the notion that all individuals have equal moral value (Sen, 1992), prioritise equal distribution of a resource across a population. Alternatively, Rawls' Egalitarianism, whilst advocating for a basic set of equal rights and freedoms, focuses on the *difference principle*. The *difference principle* aims to prioritise the most vulnerable members of society (Fainstein and DeFilipp, 2016:263), which would lead to resource allocation that ensures that those who are the least well-off reap the greatest benefits. Due to limitations of urban growth, policy and investment it might not be feasible to perfectly distribute resources according to a specific ethical principle or a specific principle might not have been developed with accessibility in mind. However many authors have shown how different ethical principles can be used to help us think about how society and institutions can be reshaped towards more equitable outcomes (Chandler, 2023). Furthermore, it is important to recognise that decision-making processes about resource allocation may produce competing outcomes or involve significant trade-offs depending on how *fairness* is defined (Fainstein and DeFilipp, 2016). Thus, there is a significant motivation for communities, planners and decision-makers to "be equipped with the knowledge and ability to reflect on different concepts of justice" (Schmitt and Hartmann, 2016:44). The outcomes of political decisions have implicit consequences for (in)equity of accessibility to urban resources across populations and regions. This informs the underlying goal of this research, to develop a framework for stakeholders to

reflect on different notions of ethics which can be incorporated into planning processes.

4.2.2 Linking Spatial Justice to Accessibility and Transportation

Accessibility is a concept which has been developed and operationalised in transportation research for the last sixty years (Batty, 2009). It may refer to potential opportunities for social interaction (Hansen, 1959), activities that can be reached (Morris et al., 1979), is influenced by contextual constraints such as transportation cost (Davila, 2013) and can be thought of as an outcome of individuals and groups being afforded opportunities by virtue of their connection to land use through transportation (Van Wee and Geurs, 2011). A wide range of accessibility metrics exist and are applied at scales ranging from the individual to regional levels, for a comprehensive overview refer to Geurs and van Wee, (2004). In this chapter we employ cumulative accessibility metrics, which counts the number of opportunities which can be reached from certain locations within given travel times, distances or costs. Whilst an alternative metric could be utilised, cumulative metrics are the simplest to calculate and communicate (Fol and Gallez, 2014; Pereira, 2019), which is an important factor for this interdisciplinary research.

It is well established that inherent characteristics of urban and transportation development and growth lead to inevitable disparities in access to amenities (Van Wee and Geurs, 2011). Although unequal access may not be problematic or even considered inequitable, it has been associated with adverse social outcomes, such as social exclusion (Lucas, 2012). Recent theoretical advancements in accessibility research have seen authors conceptually engage with alternative ethical frameworks in the context of accessibility analyses (Van Wee and Geurs, 2011; Martens et al., 2012; Pereira et al., 2017). Despite these advancements, transportation appraisal frameworks continue to typically be based on Cost-Benefit Analysis (CBA) or Multi-Criteria Analysis (MCA), which may not take equity of accessibility into account (see Section 2.2 in the Supplementary Material (SM) for detailed explanations of both). If equity of accessibility is included as a factor, most stakeholders will be unaware of the underlying ethical framework that an indicator is based on and thus overlook the inherent value biases within it (Lucas et al., 2016). A significant portion of academic research that focuses on the operationalisation of equity analysis for accessibility has applied the notion of equity normatively (Lewis et al., 2021:2). For example, one popular approach is a needs-gap analysis which quantifies "gaps" between potential demand or transit need and some measure of existing access. While these approaches measure the "gap", they tend to apply an arbitrary or descriptive reference threshold (Karner et al., 2023:16). Alternate approaches that simply evaluate existing levels of access will usually only be explicitly linked to a singular ethical framework. By far the single most popular indicator for equity of accessibility is the use of the Gini Index and Lorenz curve adapted from economics (see Van Wee and Mouter (2021) for a full review). This indicator is based on egalitarian notions of equity, which tend not to be concerned with the differences between population groups and are usually applied at the city level. Consequently it is a challenge to decompose the results and relate it to varying socio-economic neighbourhood characteristics.

4.2.3 Neighbourhood Accessibility

Neighbourhoods are considered important building blocks in cities (Patias et al., 2021) where multiple levels of social ecology converge, including "poverty, affluence, employment, family structure, violence, and criminalisation" (Sampson, 2019:8). Recent academic research has shown that neighbourhoods matter for social mobility and can shape long-term individual economic outcomes (Chetty and Hendren, 2018; Troost et al., 2023). Whilst the precise way that a border of a neighbourhood is defined has long been a concern in geography (Shelton and Poorthuis, 2019), within urban resource management, the administrative boundaries of neighbourhoods are important. They signify differences in governance by specific local councils and delineate the municipality that a neighbourhood lies within, which ultimately governs the policies, zoning laws, investment opportunities and modes of governance

applied to that neighbourhood. Over the last thirty years, there has been a global trend of state investment focusing on the individual household as the primary means of social mobility (Parnell et al., 2009), instead of investing in local neighbourhood infrastructure. Both academic research and lessons from public policy signal that linking spatial distributional justice with local socio-spatial neighbourhood characteristics is important to provide insights into the fairness of urban resource distribution within cities for different population groups (i.e. Valenzuela Aguilera and Tsenkova, 2019; Smith et al., 2020). Whilst others in the field have conducted research at the neighbourhood scale (i.e. Grengs et al., 2010), we specifically focus on developing alternative metrics of spatial justice designed for comparative purposes at the neighbourhood scale.

4.2.4 Measuring Spatial Justice

In transportation appraisals, spatial justice is typically not a primary factor of consideration or stakeholders may not be fully aware of the underlying frameworks that support specific indicators (Lucas et al., 2016:476). Whilst there are exceptions, many studies adopt a normative approach (Lewis et al., 2021:2) or utilise indicators based on only a single theory of justice that may not be linked to broader socio-economic neighbourhood characteristics. This is exemplified by the popularity of application of the Gini Index to accessibility analysis at the city scale (Van Wee and Mouter, 2021).

In reviewing the literature, it is clear that justice and equity do not boil down to a single definition (Peyton Young, 1994). Furthermore, achieving perfect equity or equality in access may not be fully possible due to inherent constraints of urban growth. However, one of the roles of urban policy is to act as a guiding force towards more just urban and transportation development outcomes (Delbosc and Currie, 2011; Litman, 2022). Thus there is a strong motivation for the inclusion of justice considerations within transportation appraisals, to support ethically informed decisions.

What may be the most appropriate definition of justice, in the context of urban development, is an important philosophical debate. However, as Lewis et al. (2021:2) state, it's very difficult to engage in a debate when "morals in transportation remain mostly invisible". Our primary contribution thus lies in the MAP framework which operationalises three well established and varying notions of justice into practical and comprehensible measures that can be applied by practitioners to monitor and evaluate accessibility at the neighbourhood scale.

Building on existing literature, we firstly apply a cumulative accessibility metric, we refer to as Neighbourhood Reach Centrality (NRC) to count the number of places of employment that can be reached specifically from each neighbourhood in each case at 15, 30, 45 and 60 minute time thresholds (refer to Figure 4.12b). This is followed by measuring spatial justice based on Egalitarian, Rawlsian, and Utilitarian ethical principles, which are three of the most applied theories within transportation literature. Based on each ethical principle, these metrics re-imagine ideal distributions of accessibility (Equality Reach Centrality, Rawls' Reach Centrality and Utilitarian Reach Centrality) and the gap (Equality Reach Gap, Rawls' Reach Gap and Utilitarian Reach Gap) between existing and ideal neighbourhood accessibility levels (refer Figure 4.12c). The Equality Reach Gap, based on egalitarian principles, prioritises equal access across neighbourhoods. Whereas the Utilitarian Reach Gap, based on utilitarian principles, prioritises greater access to neighbourhoods with larger working populations. Whilst the Rawls' Reach Gap, based on Rawlsian principles, prioritises more access to neighbourhoods which are the most socio-economically vulnerable. Each metric highlights different issues and can be directly compared through maps for deliberation by stakeholders and citizens.

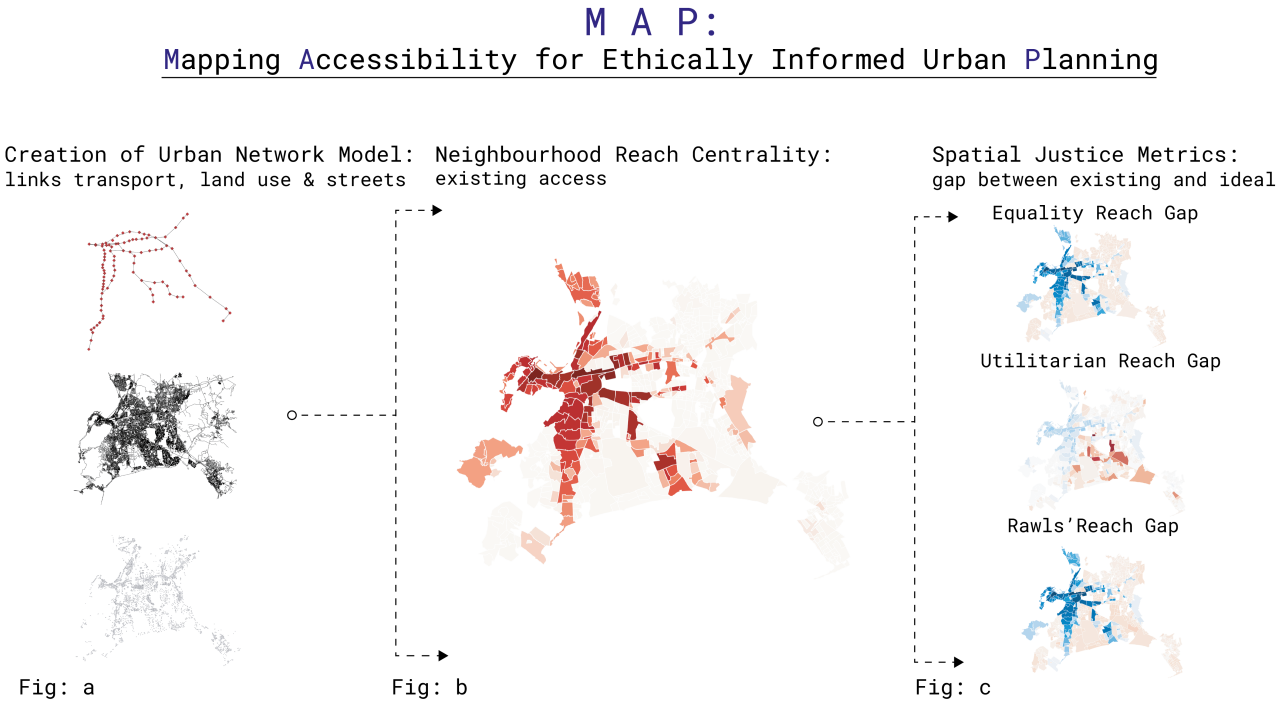


Figure 4.12: This figure presents MAP, which is comprised of three stages: 1. development of an Urban Network Model (UNM) for each case, 2. calculating Neighbourhood Reach Centrality (NRC) for every neighbourhood and 3. developing and applying metrics for Spatial Justice based on three ethical perspectives of Equality, Utilitariansm and Rawls' Egalitarianism for comparative purposes.

4.3 Case Studies

Urban Science and theory has historically been crafted from a small number of cases in the West (Parnell et al., 2009). A more inclusive urban agenda is required, especially since the majority of new urban development is taking place within the global South. Furthermore, increasingly, local governments are utilising metrics as evidence for monitoring and evaluating the effectiveness of urban service provision and policy making (Bibri, 2019, Kitchin et al., 2015). Thus, to inform theory and practice on spatial justice it becomes increasingly imperative to use metrics that can be applied across a diversity of cases.

In the interest of evaluating the applicability of MAP across multiple contrasting cases, we select three distinct and intercontinental case studies: the Metropolitan area of Cape Town in South Africa (CPT), the Metropolitan area of Monterrey (AMM) in Mexico and the Metropolitan region of Rotterdam and the Hague (MRDH) in the Netherlands. The reasoning behind this particular selection is threefold. Firstly, whilst the aim is to develop metrics which can be generally applied to enhance our understanding of spatial justice of neighbourhood accessibility to a range of urban resources (i.e. healthcare, educational facilities, green parks etc.) we specifically focus on places of employment in this study. The role of access to employment is being increasingly recognised as an important aspect of urban economics (Kawata and Sato, 2012; Wu et al., 2021). We thus consider contrasting levels of income inequality as a factor and according to the World Bank, the Netherlands has a Gini Index of 29 (one of the lowest in the world), South Africa 63 (one of the highest in the world) and Mexico 45 (positioned approximately in between the two former cases). Secondly, the first author has lived and practised as a spatial practitioner in each of the selected cities, allowing them to bring their contextual knowledge to the study. Thirdly, this research also contributes to advancing knowledge on secondary cities, which are an understudied area of research, in comparison to so-called "global cities" such as London, New York, and Mexico City (Sassen, 2014). Please refer to the Section 2.3 of the SM for

additional contextual information on each city relating to population growth, spatial morphology, and transportation.

4.4 Methodology

This work aims to develop spatial justice metrics for neighbourhood accessibility by quantifying the *gap* between *existing* opportunities and *ideal* opportunities, grounded in Egalitarian, Utilitarian and Rawls' Egalitarian ethical principles. There are three stages to our methodological framework, as depicted in Figure 4.13. We realize that within these stages, various decisions have been taken which could be shaped differently, which we encourage others to contribute to and build on.

- **The first stage** comprises developing an urban network model (UNM) for each case. Each UNM is a large graph that connects and represents each city's streets, land use and transportation systems. It utilises concepts and methodologies from previous multi-modal network studies (Luo et al., 2019) and advanced space syntax and land use modeling literature (Karimi and Chen, 2022).
- **The second stage** utilises the UNM to quantify how many places of opportunities (in this case employment) can be reached within different time thresholds (15, 30, 45 and 60 minutes) from each neighbourhood, which we refer to as *Neighbourhood Reach Centrality* (NRC).
- **The third stage** develops *ideal* Reach centrality metrics by redistributing existing access based on our interpretation of Utilitarian, Egalitarian and Rawlsian principles. Subsequently, we calculate the *gap* between the actual reach value (existing access) and the ideal reach value (ideal access) to assess whether a neighbourhood meets the requirements for spatial justice based on a particular ethical principle.

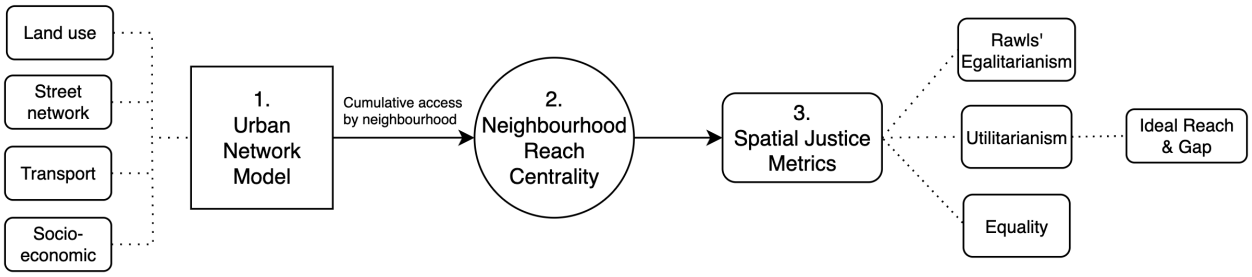


Figure 4.13: This figure presents the three stages of the methodological framework: 1. development of an Urban Network Model (UNM) 2. calculating Neighbourhood Reach Centrality (NRC) for every neighbourhood 3. developing and applying metrics for Spatial Justice based on three ethical perspectives of Equality, Utilitariansm and Rawls' Egalitarianism.

4.4.1 Creation of Urban Network Models (UNM)

An Urban Network Model (UNM) is constructed for each case by connecting land use with street and transportation networks. A UNM is a large graph G, composed of a set of vertices v and edges e. The vertices possess coordinates representing the positions of street intersections, non-residential land use or transportation stops/stations. The edges, alternatively, represent the connections between the vertices, which are streets, transportation routes, or a connection signifying an interchange between a street vertex and a land use or transportation vertex. Each edge is weighted by the time t it takes to traverse it by walking or public transport. Furthermore, we adopt a directed graph representation, meaning that all edges in the graph G have directionality. Thus, an edge connecting vertex i to vertex

j might not connect vertex j to vertex i. This representation directly reflects the nature of the streets and transportation routes, which might have different routes along onward or return journeys. We utilise NetworkX, an open-source Python library, to construct the UNM. The source of each data set and process of preparation are documented subsequently.

Processing the separate data sets

Street network: We utilise the Python library, OSMnx to download and construct street networks from OpenStreetMap, a free and open-access geographic database. The advantage of OSMnx is that the street data can be downloaded directly in a graph network format with topologically corrected street networks, preserving one-way directionality (Boeing, 2020). Each street is represented by an edge e, and each street intersection by a vertex v. Each edge is weighted by walking time, which we derive by converting the metric distance of each edge to a time based on the average walking speed of a typical person, which is approximately 5km/hour. Whilst OSM networks can differ largely by location, as Cape Town, Monterrey and the polycentric region of Rotterdam are major cities, the quality of the network is of a high standard.

Transportation data: Transportation data is extracted from varying sources and the transportation modes differ by case; refer to Table 2. The data associated with each transport mode is stored in separate tabular data sets, which can easily be converted to a graph in NetworkX. Each table for each mode includes a unique ID for each vertex, the name of each stop/station, the source and destination station/stops which denote routes, the travel time between each stop/station, and associated geometry. The data sets are, in most cases, constructed by linking official timetable data to spatial geometries associated with each transport mode downloaded from government data portals. Whilst we acknowledge travel times, in reality may differ by time of day, we utilise the first trip on each timetable as the source of travel time data. Due to data constraints, only Bus Rapid Transit (BRT), Metro, Tram, and Railway modes are included. These modes possess their own lanes or tracks separate from the general street. Information pertaining to regular bus systems, para-transit, informal transit and private vehicular usage is excluded from the analysis due to incompleteness and missing data.

Land use data: For each case, the land use data is derived from official government sources refer to Table 2. The land use data is stored in tabular format, with a unique ID, the associated coordinate geometry and land use category. The point land use data is then converted into a network of disconnected vertices. As we focus on access to places of employment, only land use associated with employment opportunities is included. In this study, it is important to emphasise that each vertex does not represent a certain number of jobs but rather *places* of employment. If the land use data is in polygon format, it is converted to a centroid geometry; if it is in a different language, it is translated to English. The land use data in South Africa is based on official zoning data, representing an entire plot. In contrast, in Mexico and the Netherlands, land use is associated with particular buildings. Although informal land use exists in Mexico and South Africa, it is not included in the analysis due to missing data.

Socio-economic data: For each case, socio-economic data at a neighbourhood level of aggregation is derived from official government sources; refer to Table 2. Whilst the precise way a neighbourhood's border is defined has long been a question of concern in geographical and urban studies (Shelton and Poorthuis, 2019), within urban resource management, the administrative boundaries of neighbourhoods are essential. They signify differences in governance by specific local councils and delineate the municipality that a neighbourhood lies within, which ultimately governs the policies, zoning laws, investment opportunities and modes of governance applied to that neighbourhood.

In each context, we focus on specific socio-economic variables, which are considered important for calculating the Spatial Justice metrics, as outlined in the *Metrics for Spatial Justice* section below.

This includes the population size of each neighbourhood and specific variables, which contribute to an understanding of levels of vulnerability within a neighbourhood. As precisely the same variables are not available across each context, they may differ, or a variable might be left out or replaced depending on what other indicators are available. The important point is that each variable indicates vulnerability within the neighbourhood population, such as lack of formal education, income, unemployment or home ownership. In the interest of the scientific validity of this methodological framework, it would be the researchers' and stakeholders' prerogative to determine which variables to include that contribute to an understanding of vulnerability within a specific context, which will notably change the selection of variables depending on the goal of a particular project.

The specific socio-economic variables for South Africa are derived from the 2011 National Census. They are total population size, average income, percentage of people employed in the neighbourhood above 18 years and percentage of people above 18 who have completed schooling. The socio-economic variables for Mexico are derived from the 2020 Census. They are the total population, percentage of people employed in the neighbourhood above *18 years* and percentage of people above 15 who have completed schooling. No data for income is available at this level of aggregation; thus, it was not included. The socio-economic variables for the Hague and Rotterdam are derived from the Central Bureau of Statistics for 2018. They are the total population, percentage of people employed in the neighbourhood, average income, and percentage of home ownership and as education level for that year was not available, it was not included.

Table 4.2: Data Set Description and their Sources

Variable	City	Data set	Sources	Description
Transport	CPT	MyCiti BRT data	Cape Town Open Data Portal www.myciti.org.za	Vertices: stations/stops Edges: routes
		Metrorail data	Cape Town Open Data Portal https://capetowntrains.sitelio.me	Weight: travel time
	AMM	Ecovia BRT data	Monterrey Open Data Portal Google API	
		Metrorey	Monterrey Open Data Portal https://metromonterrey.com/	
	MRDH	RET Tram data	South Holland Open Data Portal https://gtfs.ovapi.nl/nl/	
		RET Metro data	South Holland Open Data Portal https://gtfs.ovapi.nl/nl/	
		NL Train data	South Holland Open Data Portal https://gtfs.ovapi.nl/nl/	
Land use	CPT	Zoning data	Cape Town Open Data Portal	Vertices: land use
	AMM	Denue data	INEGI	Edges: no edges
	MRDH	Bag data	National Geo-register NL	
Streets	CPT	Road centre lines	OpenStreetMap	Vertices: street intersec.
	AMM	Road centre lines	OpenStreetMap	Edges: streets
	MRDH	Road centre lines	OpenStreetMap	Weight: walking time
Socio-economic	CPT	Census 2010	Statistics South Africa	Data aggregated to admin boundary of neighbourhoods
	AMM	Census 2020	INEGI	
	MRDH	Census 2018	Statistics Netherlands	

Linking the separate network layers

The Snkit Python library is utilised to connect the land use and transportation networks to the street network. For each case, the land use and transport vertices are added to the street network, graph G in NetworkX, as disconnected vertices. Utilising Snkit, each disconnected vertex is linked to the nearest geographically closest edge (street). A new edge forms, connecting each disconnected vertex with an existing street edge, creating new vertices on the street and dividing the street edges into new sections. All vertices and edges in G receive new IDs as part of the process. However, keeping a record of the original vertex IDs of the transportation vertices is important to allow the transportation edges to be added to G and linked to the correct transportation vertices. The weight for each edge type, including the created edges, is depicted in Table 3 in the SM. As the metric distances associated with each street edge might have changed due to them being split into new sections, the associated walking time weights of each street edge are recalculated.

Linking the networks to the neighbourhood administrative boundaries

Each street vertex is given an attribute of the name of the neighbourhood within which it is positioned. This attribute is transferred to the vertex through spatial joining with the administrative boundaries of each neighbourhood. This allows for each vertex to later be grouped by neighbourhood and linked to the socio-economic data.

4.4.2 Reach Centrality Metrics

Network centrality measures have been traditionally used to assess the significance of individual vertices within a graph based on their relative position (Sevtsuk and Mekonnen, 2012). Based on that, reach centrality metrics represent the number of opportunities, in this case, places of employment, that can be reached within a given time threshold T. In the following equations, we explain how we calculate two variations of Reach, one for individual vertices and the other for entire neighbourhoods. Neighbourhoods, in our analysis, are composed of agglomerations of vertices which fall within the official administrative boundary of each neighbourhood, which we refer to mathematically as a, in a network G. We apply different time thresholds in our analysis: 15, 30, 45 and 60 minutes, meaning the total travel time cannot be more than these threshold values. We assume here that the total travel time consists of two modalities: walking and public transport, and that the travel time for walking is maximum 15 minutes. Many studies show that people generally prefer 10 to 15 minutes of walking during one commute (Daniels and Mulley, 2013).

Reach Centrality

To define the reach of a vertex, we first introduce some notation: i, j, h are vertices. A path p from vertex i to j (denoted $i \rightarrow j$) exists *if and only if* it is possible to travel from vertex i to j via a number of edges e. We consider two travel modalities: walking (indicated with F) and public transport (indicated with P). The total travel time for a given path p is indicated by $tt(p)$. The total travel time for a path p and modality M is denoted as $tt_M(p)$. These indicate how long it takes in minutes to travel along path p.

The reach R for a vertex i within a given time threshold T is then defined as the set containing all the vertices with opportunities j for which a path exists from $i \rightarrow j$ via vertex h such that $tt_F(i \rightarrow h) <= 15$, $tt_P(h \rightarrow j) <= T$ and $tt(i \rightarrow j) <= T$. Formally, $R^T(i)$ is defined as:

$$R^T(i) = \forall j \; \exists h \; tt_F(i \rightarrow h) <= 15 \; \wedge \; tt_P(h \rightarrow j) <= T \; \wedge \; tt(i \rightarrow j) <= T \tag{4.1}$$

The total number of opportunities that are reachable from vertex i are then given by the cardinality of the set R: $|R^T(i)|$.

Neighbourhood Reach Centrality (NRC)

The Reach R of a neighbourhood a is defined as the set O of all opportunities j that can be reached from all vertices i (all street vertices in neighbourhood a) within maximum 15 minutes walking time plus maximum T minutes public transport time and a total travel time smaller or equal to T, where T in our case is either 15, 30, 45 or 60 minutes. We employ Dijkstra's Multi-Source Algorithm to find the shortest paths in the set time threshold T from vertices O to all employment opportunities j. Formally, the neighbourhood reach $R^T(a)$ set is defined as:

$$R^T(a) = \forall i \in O \bigcup R^T(i) \tag{4.2}$$

The total number of opportunities that are reachable from a neigbourhood a are then given by the cardinality of this set R: $|R^T(a)|$.

4.4.3 Metrics of Spatial Justice

We propose ideal Reach Centrality metrics, which represent what the ideal Neighbourhood Reach Centrality for each neighbourhood is based on a general interpretation of Egalitarian, Utilitarian and Rawlsian ethical principles.

Equality Reach Centrality (ERC)

ERC is based on egalitarian principles and thus represents a situation in which all neighbourhoods A have equal access to opportunities j. Thus, ERC for a neighbourhood $a \in A$ within the maximum time threshold T is calculated as the sum of all neighbourhoods' actual reach $R^T(a)$ divided by the total number of neighbourhoods $|A|$ in the network.

$$Eq.R^T(a) = \frac{|R^T(a)|}{|A|} \tag{4.3}$$

We calculate the difference between the actual Reach Centrality of neighbourhood a and its ideal ERC, referring to this as the **Equality Reach Gap** ($\Delta\ Eq^T(a)$ of neighbourhood a).

$$\Delta Eq^T(a) = |R^T(a)| - Eq.R^T(a) \tag{4.4}$$

Utilitarianism Reach Centrality (URC)

URC is based on the principle that the right action is to maximise utility for the greatest good (Bentham, 1907) and thus maximise reach to opportunities. In this case, since we focus on places of employment, the "greatest good" would be based on the proportion of the working population residing in each neighbourhood. Thus, URC for the neighbourhood a within a maximum time threshold T is calculated as the neighbourhood reach centrality $|R^T(a)|$ divided by the sum of the total population that could work W of all neighbourhoods, multiplied by the working population of the neighbourhood W_a. Utilitarian Reach of the neighbourhood a is thus proportional to the ratio of its working population to overall working population of the city. If examining opportunities for an alternate resource in the city, the population variable might focus on a different population group such as the elderly (for community spaces) or children (for schools).

$$Ut.R^T(a) = \frac{|R^T(a)| \cdot W_a}{W} \tag{4.5}$$

We calculate the difference between the actual Reach Centrality of neighbourhood a and the Utilitarian Reach Centrality of neighbourhood a, referring to this as the **Utilitarian Reach Gap** $\Delta Ut^T(a)$.

$$\Delta Ut^T(a) = |R^T(a)| - Ut.R^T(a) \tag{4.6}$$

Rawls' Reach Centrality (RRC)

RRC is based on the Rawlsian principle that social and economic resources should benefit the most vulnerable in society to the greatest extent (Fainstein and DeFilipp, 2016:263) and, thus, Reach should ideally be proportional to a neighbourhood's vulnerability level. We thus create a Vulnerability Score V(a) for each neighbourhood based on its specific characteristics across different dimensions (n) of well-being. The variables utilised for vulnerability might differ depending on what is available and useful in each context. We list the precise variables for each case in the section of the methodology where we elucidate on the socio-economic data employed in the study, such as variables related to education level, home ownership and income. We normalise the values for those dimensions between range 0-1, then sum the normalised values, dividing them by the number of values we included. In the case of our data, the higher the values were, the higher the neighbourhood ranked in terms of well-being along the specific dimension, and thus, we subtract this value from 1 so that they correspond to vulnerability scores.

$$V(a) = 1 - \frac{\sum_0^n V_n}{n} \text{ with } n \in N \tag{4.7}$$

The RRC $Ra.R^T(a)$ for a neighbourhood a within a given time threshold T is calculated through the total neighbourhood reach centrality $|R^T(a)|$ multiplied by $V(a)$ divided by the total number of neighbourhoods $|A|$.

$$Ra.R^T(a) = \frac{|R^T(a)| \cdot V(a)}{|A|} \tag{4.8}$$

We calculate the difference between the actual Reach Centrality of neighbourhood a and the RRC of neighbourhood a, referring to this as the **Rawls' Reach Gap** $\Delta Ra^T(a)$ of neighbourhood a.

$$\Delta Ra^T(a) = |R^T(a)| - Ra.R^T(a) \tag{4.9}$$

From all perspectives, if the gap metrics are 0 or above, we consider the neighbourhood to meet the requirements for justice. To analyse the results, we focus on the shapes of the distributions of the different metrics in the different contexts through maps, density plots and descriptive statistics. Whilst a positive gap might also be deemed problematic, the focus is on the neighbourhoods which have a negative gap and would form a starting point for urban planners, city officials and transportation engineers to identify, evaluate and implement possible solutions.

4.5 Results

4.5.1 Understanding mediation of access through land use and public transportation

Neighbourhood Reach Centrality (NRC) measures the number of opportunities (in this case, places of employment) that are accessible from a specific neighbourhood in given time thresholds of 15, 30, 45

and 60 minutes. The NRC distributions display how each distribution for each time threshold across the cases is distinct, emphasising that accessibility is highly time dependent (refer to Figure 4.14). The choropleth maps displayed in Figure 4.14 show the distributions of NRC at 15 and 60 minutes respectively. At a local scale of 15 minutes, neighbourhoods with the largest *NRC* values tend to be in close proximity to high concentrations of employment land uses. Whereas, at the 60-minute threshold, a neighbourhood's relationship to each region's main Central Business District (CBD), mediated through transportation infrastructure, becomes the most important factor. For example, in Cape Town the neighbourhoods which lie along the railway lines are highlighted. Whereas in Monterrey the neighbourhoods North of the Riverbed, where the majority of public transportation lies, possess the highest *NRC* values. Whilst in Rotterdam and the Hague, the areas surrounding the central train stations have the highest relative levels of access at 60 minutes. When comparing the three cases, a distinctive pattern of *NRC* distribution emerges in Monterrey and Cape Town. With increased time thresholds, the distributions gain longer right tails, suggesting that only a minority of neighbourhoods are reaping significant benefits from access to public transportation with increased time. Whereas in Rotterdam and the Hague, a contrasting pattern is observed. The entire distribution shifts to the right, indicating that many more neighbourhoods benefit with increases in time. Whilst the *NRC* is a useful measurement to enhance understanding of existing conditions, it does not reveal any information on the fairness or equity of these distributions, leading us to analyse the *Neighbourhood Reach Gap* (NRG) results.

4.5.2 Spatial justice is time and value dependent

The *Neighbourhood Reach Gap* (NRG) measures the gap between the *existing* and *ideal* levels of access to places of employment; if the gap is below 0 for a specific neighbourhood, it indicates that this neighbourhood does not meet the requirements for spatial justice from a particular ethical framework. As each case varies significantly, in scale and urban morphological characteristics, we do not focus on a direct comparison of the differences between the absolute values between them. We rather make a general comparison between the shape of each distribution and how it changes with temporal scale in relation to "0", which would indicate no gap between existing and ideal values (refer to Figure 4.15).

There are three overarching shared observations across all cases and ethical perspectives. Firstly, a neighbourhood which meets the requirements for justice from any of the ethical perspectives at a local temporal scale (i.e. 15 minutes) might not meet the requirement from the same perspective at a global temporal scale (i.e. 60 minutes), as shown in the Figure 2.5 in the SM. This result draws attention to scale as an important consideration when measuring and conceptualising accessibility within a justice framework. A neighbourhood at a local scale (i.e. 15 minutes) might possess relatively sufficient access due to its proximity to local places of employment, but at a more global scale (i.e. 60 minutes) have relatively unequal or inequitable access due to inadequacies in connections to the main CBD mediated through transportation (See the maps in Figure 4.15 and Figure 2.6 in the SM). Secondly, the minimum and maximum gap values become more extreme from 15 to 60 minutes across all the cases and perspectives, denoting that inequalities widen with increased temporal scale. Thirdly, across all perspectives the number of neighbourhoods which meet the requirements for justice decrease with time in both Cape Town and Monterrey and increase in Rotterdam and the Hague, as can be seen from the shifting distributions in the density plots in Figure 4.15. Suggesting that the transportation system in the Netherlands is working to enhance equity, whilst only a few neighbourhoods benefit in the other two cases from the access provided by transportation included in the study.

There are a number of specific contextual insights which are worth highlighting. The URG choropleth map of Cape Town visualised in Figure 4.15 illustrates that the neighbourhoods that possess extreme deprivations are areas which were primarily zoned non-White during Apartheid and thus have a long history of cumulative disadvantage. This includes the townships of *Mitchells Plain* and *Khayelitsha*, which have been subject to intense population growth, particularly through rural-to-urban migration

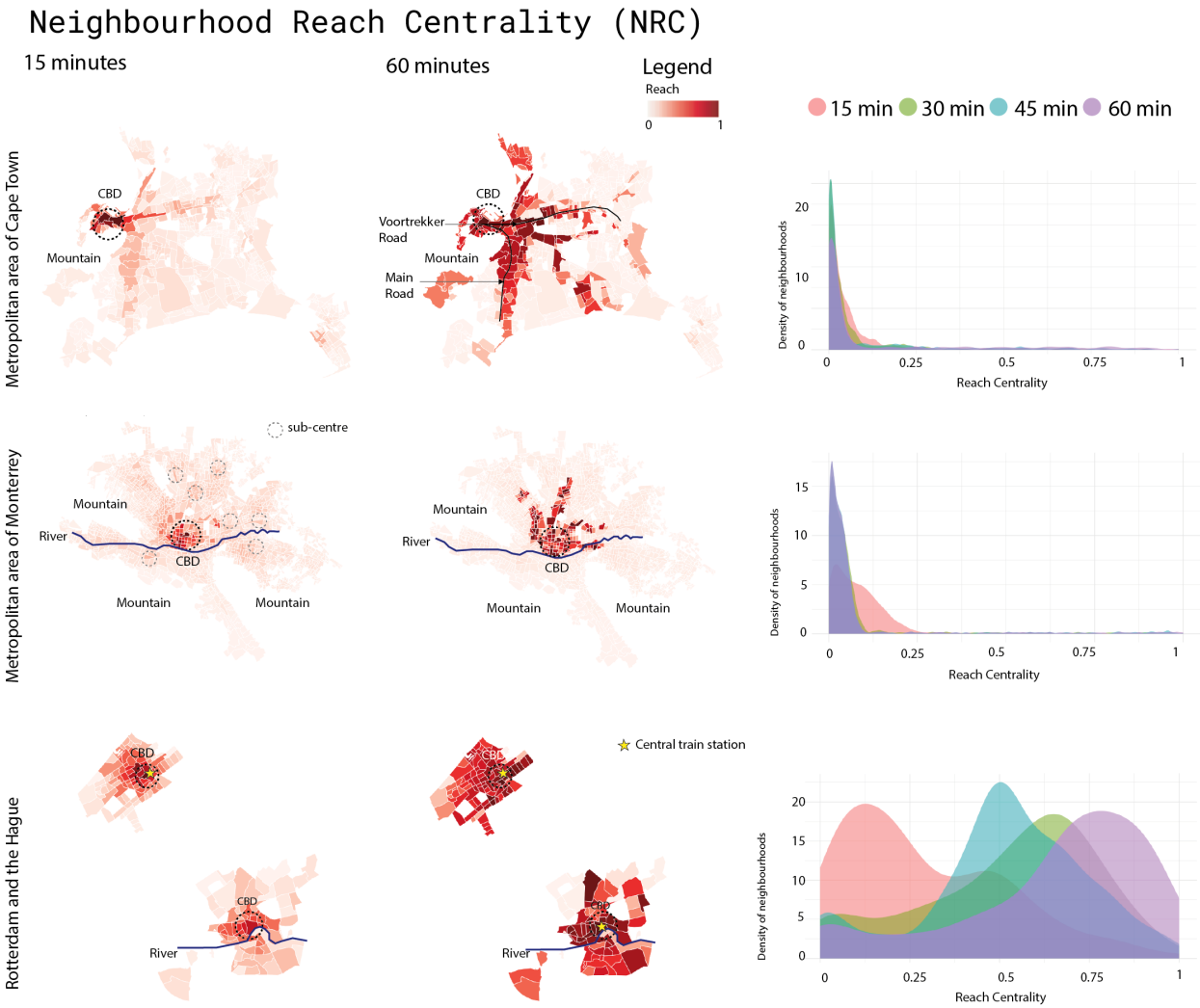


Figure 4.14: This figure visualises each case's NRC distributions at the time thresholds of 15, 30, 45 & 60 minutes. The maps highlight the spatial positioning of neighbourhoods at 15 & 60 minutes, & the density plots highlight the shape of each distribution at all time thresholds. The metric is scaled between 0-1 to facilitate comparison within cities.

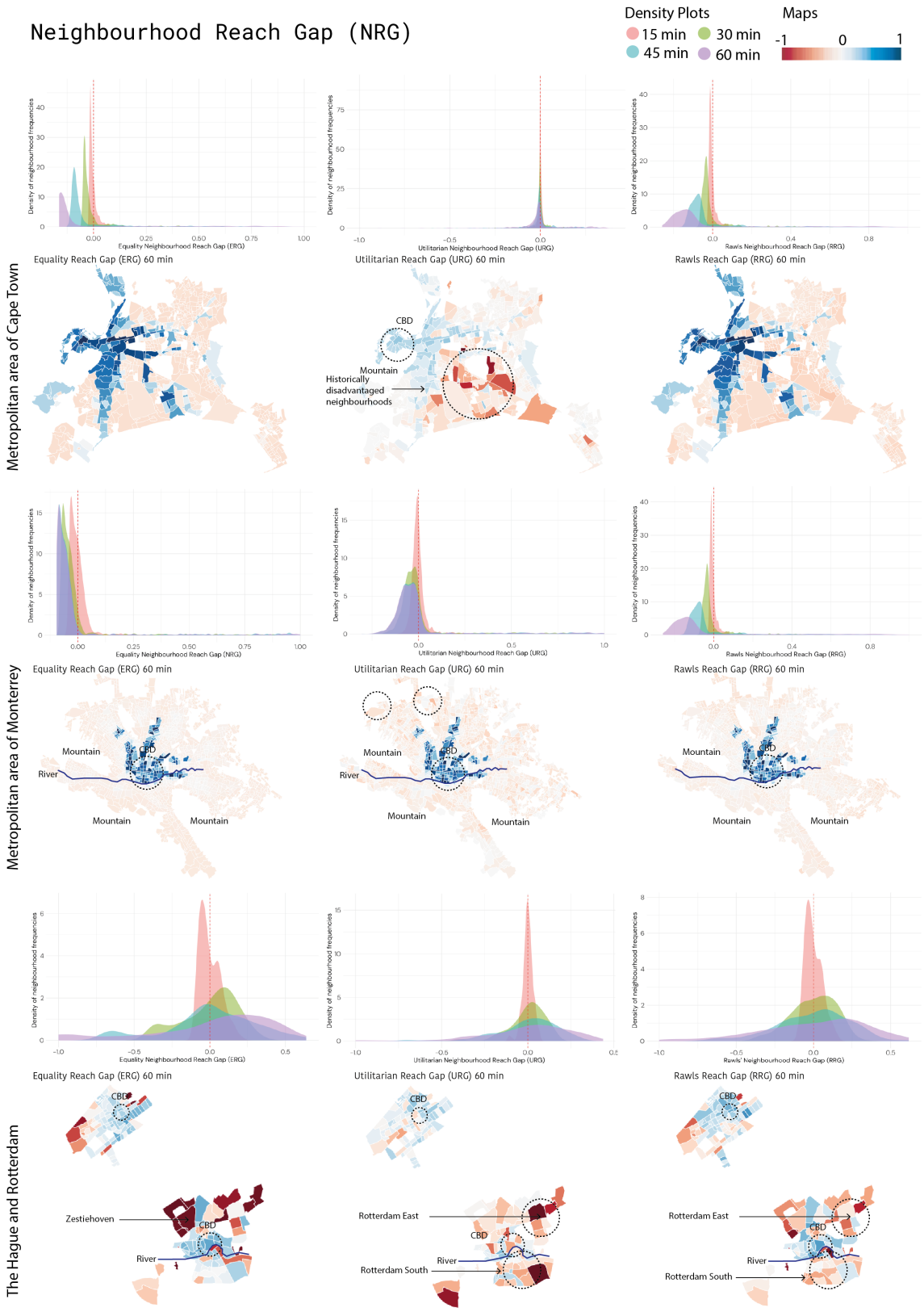


Figure 4.15: The density plots show how the Neighbourhood Reach Gap (NRG) distributions change with time thresholds of 15, 30, 45 and 60 minutes according to three ethical perspectives of Equality, Utilitarianism and Rawls' Egalitarianism. A gap signifies whether neighbourhoods meet the criteria for spatial justice according to a particular ethical perspective. The choropleth maps highlight the NRG gaps for each ethical perspective and case at 60 minutes only, normalised between -1 and 1 to facilitate comparison within cities. A negative gap is highlighted in shades of red and a positive gap is highlighted in shades of blue. The distributions are all centered around "0", as that is key in understanding if it is a negative or positive gap.

since 1994 (Turok, 2001). In Monterrey, the same neighbourhoods are emphasised across the perspectives, due to the high centralisation of the limited public transportation infrastructure. However, the URG map in Figure 4.15 reveals that the most deprived neighbourhoods are positioned on the city's outskirts in the North. These neighbourhoods developed recently over the last 30 years and thus have not been adequately planned and serviced with transportation infrastructure (Carpio et al., 2021). In Rotterdam, specific neighbourhoods in *Rotterdam South* and *East* are emphasised from both Utilitarian and Rawlsian perspectives, refer to Figure 4.15. These neighbourhoods have a long history of struggling socio-economically (Nelson et al., 2024). Various affluent neighbourhoods in the North are also emphasised, such as *Zestiehoven*, particularly from an Equality perspective, when no socio-economic factors are taken into account. This is due to these neighbourhoods being extremely isolated through both lack of transportation and places of employment. In daily life residents of these neighbourhoods probably rely on private vehicle use, which was not included in the analysis.

4.6 Discussion

Several factors shape spatial justice in cities

The following discussion focuses on several factors that shape spatial justice within cities based on the comparative assessments presented in this chapter.

Ethical Perspectives

Each gap metric is based on an underlying ethical value and yields markedly diverse outcomes across the cases. The analysis highlights that it is not sufficient to only consider existing levels of accessibility or accessibility based on solely one ethical perspective. A specific neighbourhood might appear to have sufficient access or meet the requirements for justice from one perspective but not from an alternate perspective. Each ethical perspective is biased towards a specific definition of fairness, which might, for example, prioritise the majority of the population or, alternatively, the most vulnerable in society. Whilst this insight may seem relatively evident from the outset, our framework provides an avenue to investigate the implications of selecting different notions of equity to deepen our understanding of distributive spatial justice. By contrasting and visualising alternate metrics, we can better clarify the competing trade-offs in decision-making processes to guide urban policy towards more just outcomes.

Temporal Scale

The *NRC* and *NRG* metrics are highly time-dependent across the cases, which aligns with and builds on previous work showing that time thresholds for cumulative accessibility analysis are important considerations (Pereira, 2019). Similarly, time and, hence, access afforded by infrastructure are important factors when measuring spatial justice. At a local scale (i.e. 15 minutes), neighbourhoods that meet the requirements for justice from a particular perspective tend to be in proximity to a diversity of local land use. In contrast, at a more global scale (i.e. 60 minutes) neighbourhoods which meet the requirements for justice tend to have access to the main CBD of the region mediated through transportation infrastructure.

Across all perspectives and cases, the minimum and maximum gap values increase with time. This underscores the tendency for inequalities to widen with larger temporal scales, resulting in those with access to public transit and in proximity to the CBD gaining many more benefits in comparison to local opportunities, which are often insufficient for seeking better livelihoods in large cities. In Cape Town and Monterrey from all perspectives the percentage of neighbourhoods meeting justice requirements decreases with time. This highlights how the transportation infrastructure that is included in this analysis, only benefits a small number of neighbourhoods. From all perspectives, in Rotterdam and the Hague, larger time thresholds tend to result in more neighbourhoods meeting the requirements

for justice, highlighting the strength of the Dutch transportation system as a global connector.

Spatial morphology

Spatial morphology shapes the spatial form of each context and thus is an important factor to consider within accessibility analyses. For example, the northern and southern sides of Monterrey and Rotterdam are divided by rivers, and the neighbourhoods on either side tend to possess varying justice outcomes (refer to Figure 4.15). This may be an example of natural features forming boundary conditions, which reinforce particular social conditions, as highlighted in other studies (i.e. Tóth et al., 2021). Cape Town and Monterrey have been subject to rapid urban growth; their populations have doubled in the last 30 years, with the majority of urban growth taking place on cheaper land on the outskirts of these cities (Carpio et al., 2021; SACN, 2016). From a Utilitarian perspective, in both these regions, it is clear that these neighbourhoods are not adequately serviced with formal transportation or places of employment.

Sociological conditions: "forced" versus chosen "exclusion"

In some cases, wealthier neighbourhoods do not meet the requirements for justice. This may be due to an issue of "forced" versus "chosen" exclusion and the fact that many of their residents would own private vehicles, which is not considered in our analysis. In Cape Town and Monterrey, many wealthier neighbourhoods are segregated through their positioning on the foot of the mountains, which forms a natural boundary to city growth. In Rotterdam, many wealthier neighbourhoods are also positioned further away from the CBD, closer to the rural countryside. Wealthier residents might choose to live in more isolated neighbourhoods due to prime real estate often being located adjacent to beautiful natural features and the access afforded through private car ownership.

4.7 Conclusion

Developing benchmarks for spatial justice allows us to test theoretical considerations and ensures that they have relevance and applicability across cultural, geographical and economic contexts towards a more inclusive urban agenda (Parnell et al., 2009; Robinson, 2016; Robinson and Attuyer, 2021).

It is important to recognise that the data utilised in each of the cases is incomplete. Data on paratransit, bus, private car ownership, cycling networks and informal land use would enhance the results. Additionally the study is limited by the aggregation of the socio-economic data to the administrative neighbourhood boundaries, which could potentially conceal experiences of accessibility related to individual factors such as age, gender, or perceptions of safety. Furthermore the size of the boundary will influence the scientific results; this is a well established phenomenon in geographical research known as the Modifiable Area Unit Problem (MAUP). With these limitations in mind, there are specific recommendations which are derived. The south-east neighbourhoods in Cape Town and larger neighbourhoods on the outskirts in Monterrey have been subject to rapid growth over the last 20 years and are severely under-serviced by both bulk transportation infrastructure and employment opportunities. In both these contexts a multi-layered strategy that unlocks land use for economic development combined with expanding bulk infrastructure is necessary for equity of opportunity. From both Rawlsian and Utilitarian perspectives, a comprehensive urban strategy to address the clear deprivations in Rotterdam South is required in both transportation connectivity and land use proximity. Future research could focus on incorporating more detailed transportation data, informal services and the number of jobs at each place of employment as well as applying MAP to analyse neighbourhood accessibility to alternative amenities such as green spaces or educational facilities. Furthermore, as we only consider generic times for each transport mode, a richer understanding could be derived through incorporating multiple times of the day for travel. Finally MAP could also be expanded to include additional metrics

based on alternative theories of justice, such as sufficientarianism.

Planners, stakeholders and residents need to be equipped with the knowledge and ability to reflect on different concepts of justice (Schmitt and Hartmann, 2016:42). This is especially significant as participatory practices and co-creation are becoming important pillars of municipal planning worldwide (UN-Habitat, 2021). Policy should act as a guiding force towards more just urban and transportation outcomes. Whilst perfect equity or equality might not be possible, the MAP framework can be used to monitor and evaluate levels of access from different ethical perspectives. Furthermore, it offers the opportunity to highlight strengths or weaknesses of proposed interventions, especially in those neighbourhoods which possess negative gaps. The metrics allow for the pinpointing of particular issues in each neighbourhood at different temporal scales, such as a deficiency in access to local land use or connections to transportation infrastructure for wider debate. There are clear benefits to the application of these metrics; however, we do not claim that they represent an absolute truth or will resolve issues of justice. Metrics and benchmarks should always be applied critically; they are limited methodologically and subject to technical issues (Kitchin et al., 2015). Nevertheless, they can bring moral clarity to the alternatives we face, insights to explain various aspects of urban life and the implications of various urban policies on urban form and spatial justice.

Constructing Just Mobility Futures

Chapter 5 focuses on all three lenses identified in the 2nd Chapter, namely: a *policy and stakeholder* lens, *accessibility* lens and *distribution* lens. The previous chapter established the MAP framework, which operationalises different theories of justice in a comparative framework. This leads to the advancement of the MAP framework through examining how it can be used as a tool to inform decisions for future planning in this chapter. Scenario planning has become a common approach within transportation research to understand the varying impacts of transportation planning. Whilst there has been growing concern over the equity impacts of public transport investments, equity of access considerations remain an underdeveloped area within transportation scenarios research. Utilising the case study of Cape Town, in South Africa, several transport scenarios are collectively developed through stakeholder engagement by analysing a number of parameters that have been identified as significant operational factors and policy levers. Overall, the study highlights how the adoption of transportation solutions towards greater accessibility is not only an engineering problem, but a *human problem* related to institutional capacity, trust, coordination, community agency and political vision. A preprint of the paper can be found here: Nelson, R., Verma, T., Warnier, M., Pearce, B., 2025. Constructing Just Mobility Futures. https://doi.org/10.2139/ssrn.5141604

"All urban dwellers can see their power in the thinking behind the process of changing the city... through discussions, debates, compromises, and civil arguments."

– Shane Epting (2023)

5.1 Introduction

The United Nations' Sustainable Development Goals (SDGs) call for planning that fosters a more equitable and socially inclusive urban future. Central to the United Nations' approach to human and sustainable development is Amartya Sen's Capabilities framework, which proposes that development should focus on expanding each person's capability to lead the life they choose by ensuring meaningful access to opportunities that improve their well-being (Sen, 1999). Empirical studies consistently show that barriers to accessibility can trap individuals in a cycle of poverty (Nijman and Wei, 2020). Consequently realising more socially inclusive and just development requires addressing the factors that will improve access to socio-economic opportunities such as employment (Zhu and Shi, 2022), healthcare (Pereira et al., 2016), and education (Troost et al., 2023).

Transportation and urban development takes place within a complex institutional context and thus can be considered a wicked problem as it is not only technical in nature, but also political (Machiels et al., 2023; Rittel and Webber, 1973). Multiple forces, ranging from private investment, policy decisions to climate change drive development in ways that are often difficult to predict leading to high degrees of uncertainty. This complexity poses a challenge when planning for a more just future, as traditional predictive data and modelling techniques struggle to account for uncertainty.

In this chapter we employ scenario planning as a planning support tool, as it explicitly embraces uncertainties, with the intent of preparing organisations to adapt to multiple outcomes. Scenario planning has a long history of being applied across different sectors such as the military (Ringland, 1998), energy (Blondeel et al., 2024) and water management (Dong et al., 2013). It has become a common approach within transportation research to understand the varying impacts of transportation planning under different future conditions (Lyons et al., 2021). By focusing on the uncertainties which shape the future and how they could change, scenarios generate a representation of a system and are not an exact science (Paddeu and Lyons, 2024).

Although equity of access has been a concern for a long time in transportation accessibility research (Pereira et al., 2017), within transportation scenario planning it is an underdeveloped area (Pan et al., 2024). If equity is not considered within scenarios, it presupposes that the benefits and burdens associated with different future states are evenly distributed across a population and/or region. Empirical work from transportation accessibility literature has shown this not to be the case (Lucas, 2012; Lucas et al., 2016). Building on existing literature, we connect equity of accessibility and transport scenario planning research to explore how equity can be incorporated into scenario planning as a planning support tool, utilising the City of Cape Town (CoCT), in South Africa as a case study. The CoCT is South Africa's second largest city characterised by vast spatial inequalities, with the wealthy residing around existing economic nodes and low-income settlements situated on the urban periphery (Cooke et al., 2019).

In this research, we present four transport scenarios for the CoCT in the form of coherent narratives based on participatory engagement through an interactive workshop and semi-structured interviews. To explore the equity impacts of each scenario, they are transformed into representative urban network models. Using the models, accessibility to places of employment is calculated for each neighbourhood and evaluated using the Mapping Accessibility for Ethically Informed Planning (MAP) comparative equity framework developed in the previous chapter. This framework operationalises three well-established notions of equity drawn from moral and political philosophy. Ethical principles have historically been employed by philosophers to guide thinking about reshaping society towards more just outcomes. Rather than imposing a single ethical framework that may not account for local needs or preferences, we employ a comparative framework to highlight different issues, such as unequal access, lack of access by the socio-economically disadvantaged, or even by the majority of the population. In doing so, we showcase how different ethical frameworks can be operationalised to allow

communities to identify their specific priorities and move in a direction that best aligns with their values. Our approach is situated within the broader notion of the *Right to the City*, as articulated by Harvey (2003), Lefebvre (1968), and others. This concept emphasises the collective power of communities to shape future urbanisation processes. Ultimately, communities and stakeholders must decide how they define justice, while our role is to provide tools that help them explore diverse pathways towards achieving the SDGs.

The remainder of this chapter is structured as follows: through a literature review we connect transport scenario planning to equity of accessibility research, followed by a description of the Methodology, comprising of four stages. Subsequently the Results are presented, followed by a discussion of their implications both for research and the CoCT. We conclude by reflecting on areas for future research.

5.2 Linking scenario planning and equity accessibility research

5.2.1 Background to scenario planning

Contemporary scenario planning emerged as a strategic foresight tool developed by the think tank, the RAND Corporation, in the 1950's, to support the United States Military in investigating policy alternatives (Ringland, 1998). The technique focused on developing alternative "narratives" of the future, written from the perspectives of different people in the future, referred to as scenarios. In the 1970's, scenario planning gained popularity as a business strategy tool, when it was adopted by the company *Shell* to help senior management think about long-term, business challenges (Menzies and Middleton, 2020: 42). In the 1990's scenario planning began to emerge as a strategic urban planning tool to develop *desired* urban visions for the future (Avin and Goodspeed, 2020). More recently, the focus has shifted to create scenarios that stakeholders may not consider as desirable (Avin and Goodspeed, 2020). The purpose being to deepen an understanding of uncertainty within future development, such as changing levels of economic growth or the public's willingness to support policies towards carbon neutrality (Lyons et al., 2018).

5.2.2 Defining a scenario

Whilst many definitions for a scenario exist, it can broadly be understood as a representation of a potential future shaped by a specific set of driving forces, which does not align with any current or proposed policies (Shaheen et al., 2013). Contemporary scenario planning embraces uncertainty by accepting that the future is not a static and/or predictable outcome, but is shaped by a set of driving forces which could interact in complex ways. In some cases, a scenario is defined as a result of both driving forces and existing policies. However, in this dissertation, a scenario specifically refers to a "possible world" that does not take into account any current or proposed policies. Within urban and transportation studies, scenarios are either represented through qualitative descriptions that describe a certain state or, they are embedded in quantitative models (Pan et al., 2024:87). In this study, we represent scenarios through both descriptive narratives and quantitative models.

5.2.3 Different types of scenarios

Avin (2016) distinguishes between three modes of scenario planning: predictive, normative and exploratory scenarios. A predictive scenario, sometimes called an expected, baseline or trend-line scenario, tends to reflect a singular situation, that is deduced by analysing past trends to determine what the most likely scenario will be. Whereas a normative scenario typically reflects a single *desired* state for the future. Normative approaches to scenario-based planning tend to assume a larger degree of control to realise the desired plan and often do not fully address uncertainties about how the future will unfold (Wiechmann, 2008). Whilst not formally referred to as a scenario, urban planners will typically design one singular urban or regional plan, based on a desired future by authorities and/or

stakeholders. In contrast to the other categories, exploratory scenarios will embody a range of alternatives that weight the effect of various driving forces differently to explore avenues of development. Usually exploratory scenarios are developed through creative thinking and debate. Scenario development is ideally a participatory process that helps explore uncertainty about the future (Lyons et al., 2021). In developing scenarios, those participating will draw upon the mental models they have about the world based on their knowledge, experience and values (Paddeu and Lyons, 2024). Cognitive overload in scenario planning is a significant challenge and thus the recommended number of scenarios is between three to five scenarios (Amer et al., 2013; Lyons et al., 2021).

5.2.4 Equity of accessibility in scenario development

There is an extensive body of literature on accessibility research, developed over the last 60 years within transportation and urban planning-related fields (Batty, 2009). In planning, accessibility refers to the potential opportunities, both social and economic, that individuals or groups are able to reach within a specific time threshold, relating to transportation infrastructure, land use distribution and individual characteristics such as income and gender (Geurs and van Wee, 2004). Researchers measure accessibility in many different ways, from cumulative measures that simply count the number of opportunities that are reachable to more complex measures which, for example, weight destinations by distance (gravity measures) and/or take into account aspects of competition (Floating Catchment Area Methods) (Demitiry et al., 2022).

Despite significant advancements in research, there is still a wide gap in the implementation of accessibility measures in planning (Silva et al., 2017). Transport planning in practice tends to be forecast-led by expectations of future demand. Lyons et al. (2024) refer to this as the "predict and provide" approach, which focuses on optimising for a singular future, based on demand estimates. This approach overlooks both latent demand and conceals uncertainty about the future. Latent demand refers to the potential demand for travel that is not currently being realised due to various constraints (i.e. congestion, lack of infrastructure, pricing, or inconvenience) representing the unmet need for mobility that would materialise if conditions were improved (Clifton and Moura, 2017).

From a distributive justice perspective, equity of accessibility is concerned with the fairness of distribution of benefits and burdens across a city's population through access to urban resources (Pereira et al., 2016). From a procedural justice perspective, equity of access is concerned with the fairness of the processes which shape the way access to resources are distributed across a city (Harvey, 2003). Moving towards a more just future requires thinking about equity of access from both distributive and procedural perspectives. Strategic scenario planning is a useful methodology for identifying the factors which shape accessibility in a city to explore alternative future scenarios. However Pan et al. (2024) conduct a systematic literature review of equity in transport scenario planning finding that very few studies include quantitative evaluations of equity and involve community representatives. As a consequence many strategic scenarios are developed on the assumption that the benefits and burdens will be evenly distributed across regions and populations. This leads to the main concern of this chapter, which focuses on how we can incorporate equity and justice considerations into scenario planning.

To address this concern, requires answering the question, *how do we define justice*? Historically, philosophers have developed ethical theories to guide thinking about what justice means. Each ethical theory offers unique insights into how resources and opportunities can be distributed (refer to Table 4 in the SM). Sen (2006) makes the distinction between transcendental and comparative approaches of justice. Transcendental theories of justice argue for a perfect ideal from which only then justice is achieved. In contrast, a comparative approach concentrates on ranking alternative societal arrangements by whether some arrangement is less or more just. For example, if a policy is introduced which improves society in some way, a comparative approach would argue that society has moved towards

a more just condition, whereas from a transcendental approach, society would still be considered unjust. Whilst transcendental approaches are needed as they have long provided motivation for action towards social change, Sen (2006) asks us to consider the practical implications of them. Realistically no policy is going to create a perfectly just condition in a world where there is so much inequity, across human, environmental and planetary lines (Sen, 2006). A comparative approach allows us to rank different states by how *more* or *less* just they are. Harvey (2003:939) enriches this argument, by advocating for citizens' right to the city, he states, "the right to the city is not merely a right of access to what already exists but a right to change it to our heart's desire". Central to this notion is that justice needs to be contextualised and citizens have a right to decide how they would like their cities to be shaped. This emphasises the importance of stakeholder and citizen engagement within scenario planning. Based on this discussion, there are two primary insights which inform this chapter. Firstly, a comparative approach allows for a ranking of different states, which is more applicable to the reality of the world we live in. Secondly, people have a right to participate in decision making processes related to the development of their cities, and thus as an implication, should have a voice in how *justice* within that context is defined.

This differs from typical approaches adopted in equity of access analysis. Although there are notable exceptions, many studies take a normative stance without referring to a particular ethical framework (Lewis et al., 2021:2) or rely on indicators grounded in a single theory of justice, which may not account for wider socio-economic neighbourhood dynamics. For example, Van Wee and Mouter (2021) conduct a systematic literature review, finding that the use of the Gini Index for equity of accessibility is by far the most applied indicator, underpinned by egalitarian principles.

In contrast, we adopt a comparative approach to prevent any single theory from dominating the conversation, enabling a broader range of issues to emerge. By examining justice through multiple lenses, communities can deliberate on the trade-offs between maximising overall societal benefit, addressing the needs of the least advantaged, and ensuring equal opportunities for all. This flexibility is essential for navigating the complexities of accessibility and fostering more inclusive, equitable solutions that reflect the diverse needs of communities - placing them at the heart of urban development. To support this approach, we use the MAP comparative framework, which draws on Rawlsian, Equality-based, and Utilitarian theories (Nelson et al., 2025). MAP operationalises justice metrics in a way that allows for side-by-side comparison of how well different scenarios close the gap between current and ideal levels of access at the neighbourhood scale. These three theories are among the most widely applied in accessibility analysis, and MAP enables their comparative use without privileging one as inherently *most just*. Instead, it highlights different dimensions of justice, empowering stakeholders to debate and determine which priorities matter most in their specific context.

5.2.5 Research question

There is a wide body of literature on scenario planning for strategic urban and transportation planning. Furthermore, agencies around the world are increasingly adopting it as an approach. Whilst accessibility indicators can be utilised to assess scenarios, there is still a wide implementation gap noted by Silva et al. (2017) and others. It is important to bridge that gap, with easy-to-understand measures and frameworks that can be translated to practice. Therefore, the primary research question of this work is: *How can we incorporate explicit comparative equity considerations into scenario planning to explore accessibility impacts of transportation alternatives?*

5.3 Methodology

This work aims to incorporate explicit comparative equity considerations into scenario planning to explore accessibility impacts of transportation alternatives in the CoCT. There are 4 stages, as depicted

in Figure 5.16:

- In the first stage, a stakeholder and institutional analysis of transportation governance is conducted. The intent is to identify the organisational actors involved in the operationalisation of transport and the policies used to govern them.
- The second stage focuses on stakeholder engagement to incorporate a diverse range of perspectives and views to inform the scenario creation.
- In the third stage, the transcripts are analysed through thematic analysis to identify themes which are organised into cohesive narratives representing scenarios. We validated both the drivers and scenarios through expert interviews.
- In the fourth stage, the accessibility conditions to places of employment in each scenario are evaluated using a comparative equity framework.

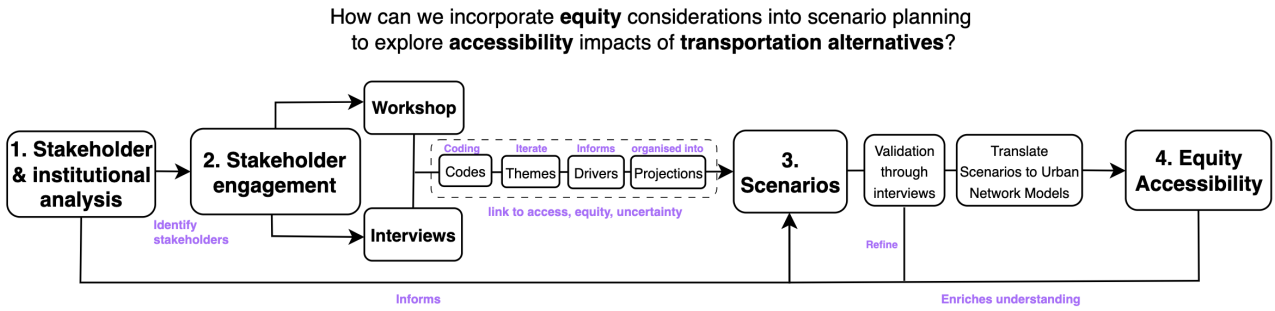


Figure 5.16: This figure depicts the four stages of the methodology. A stakeholder and institutional analysis allows for the identification of stakeholders who are selected to participate in interviews and a workshop to inform the scenario creation. The transcripts are thematically analysed to identify key drivers of development and accessibility that are organised into cohesive narratives which form the scenarios. The scenarios are transformed into representative urban network models. The accessibility conditions to places of employment in each scenario are evaluated through a comparative framework.

5.3.1 Stage 1: Stakeholder and institutional analysis

The purpose of institutional and stakeholder analysis is to provide insights into the broader visions and goals for development in the CoCT, identify relevant stakeholders, and gain insight into the operationalisation of transport. We adopt a multi-actor framework, which conceives the policy making as a social process enacted between stakeholders, rather than a purely rational endeavour to find the most optimal solution to a problem (Hermans and Thissen, 2009:808). Through a revision of important policy documents (e.g. the Spatial Planning and Land use Management Act, 2013) the policy aims, characteristics of each public transport system (e.g., railway) and stakeholder entities (e.g., local government) are identified. Each entity is mapped as a block in Figure 5.18 with the relations between them indicated through arrows and the main operating/policy levers.

5.3.2 Stage 2: Stakeholder engagement

Each of the main stakeholders is shown in Figure 5.18. We contacted stakeholder representatives of each through email. In total, we had 7 respondents and conducted 7 semi-structured stakeholder representative interviews. In addition, we recruited a group of 30 citizens and professionals in the urban sector to conduct an interactive workshop. The purpose of the stakeholder engagement was to identify key drivers of development and accessibility to inform the scenarios.

Each interview was organised around particular themes to facilitate a deeper understanding of how each representative perceives the broader transport system, critical uncertainties, vision for future development and barriers related to their vision. This is a very common approach adopted in the social sciences for semi-strcutured interviews. As evidenced by Knott et al.'s (2022) extensive review on the topic, they are usually ordered around a number of themes, which form the basis for a conversation between the participant and researcher. This approach is very useful for engaging with the experiences of the participant and allows flexibility in the research process, which might be different from a survey or structured interview, which is comprised strictly of precisely the same questions for each participant (Knott et al., 2022). Each interview was between 45-60 minutes and was digitally recorded. Section 3.2 in the SM contains the list of questions used to guide the interviews.

The aim of the workshop was to facilitate a collaborative process to collectively consider barriers and drivers of accessibility within the CoCT. In collaboration with a local NGO, Young Urbanists South Africa, we recruited participants. In total, 30 participants signed up for the workshop with 55%, who identified as women, and 45%, who identified as men. The majority of participants were either working or studying in the sectors of Urbanism, Architecture, Research, Sustainability or Civil engineering. They were divided into five groups and given a series of questions to answer and discuss, as listed in the Section Section 3.2 in the SM. After an hour, each group presented their ideas through posters, maps and diagrams for wider discussion. The workshop was documented through recordings, photographs, videos, and expert note taking.

5.3.3 Stage 3: Scenario development

The interview and workshop transcriptions were analysed using thematic analysis to identify the core themes related to accessibility and drivers of future development. Thematic analysis is a method used to analyse qualitative data, involving the identification of patterns in a data set, which are then interpreted for their inherent meaning (Braun and Clarke, 2006). The first step involves highlighting a segment of text - a few words, or longer excerpt - which is given a label. Each label communicates a summary of what is present in the highlighted text, such as "institutional capacity". This is referred to as the coding process; it is conducted iteratively until a coherent set of codes is applied across all transcripts. The codes are organised into meaningful themes, to identify patterns and relationships, refer to Table 5 in the SM for examples. The themes go beyond merely being recurring elements as they embody meanings that link the ideas discussed to equity, accessibility and future development. These themes are based on our own underlying theoretical knowledge and main research question.

The thematic analysis informed an enriched definition of accessibility and identification of 10 main drivers of change in Cape Town, which were coherently organised to develop scenario storylines. Each driver was weighted to project various states that it could exist within, refer to Table 8 in the SM. For example, one of the drivers is, "community agency", which could be high, low or somewhere in between. We organise the drivers into narratives, ensuring that the combination of drivers which inform a specific scenario can reasonably co-exist. For example, it is not reasonable to believe that different transport modes will be integrated if institutional relations are low, as integrated planning requires strong institutional mobilisation. This ensures that the final scenarios are consistent. As cognitive overload is a challenge, the advised number of scenarios is between 3-5 (Amer et al., 2013). We thus develop 4 scenarios. The scenarios were presented to three policy and transportation experts, who work in the CoCT, where they were asked to validate the drivers and scenarios for relevancy, consistency and coherence.

5.3.4 Stage 4: Measuring Equity of Access through MAP

This section outlines the implementation of the Mapping Accessibility for Ethically Informed Urban Planning (MAP) framework, developed from the work of Nelson et al. (2025). The framework consists of three main components, illustrated in Figure 5.17. First, MAP enables the calculation of network accessibility by assessing the actual cumulative access of each neighbourhood, within each scenario, to places of interest, in this case places of employment. This is termed *Neighbourhood Reach Centrality* (NRC). Second, MAP supports the computation of ideal accessibility scores using three frameworks:

- Equality Reach Centrality (ERC), based on principles of equality;
- Utilitarian Reach Centrality (URC), aligned with utilitarian goals;
- Rawls' Reach Centrality (RRC), grounded in Rawls' egalitarianism

Finally, MAP allows for spatial comparison between actual and ideal access of each scenario by mapping the gap between them. In all three frameworks, a gap value of zero or greater indicates that a neighbourhood meets or exceeds the respective justice criterion. While excessive access (positive gaps) may raise concerns of fairness, our analysis primarily focuses on under-access, highlighting areas for potential intervention by urban planners and policymakers.

Access to employment opportunities has long been a central theme in accessibility research (Levinson, 1998), with the jobs-housing balance frequently shaping local and regional planning efforts (Cervero, 1996). Recent trends indicate rising commute times as workers relocate further from job centres in search of affordable housing (Blumenberg and King, 2021). Increasingly, access to employment is recognised as critical to improving livelihoods (Lucas, 2012), reinforcing its importance as the focal point of this study.

The implementation of MAP involves a series of steps, which are summarised below.

Creation of urban network models

The first stage in applying the MAP Framework requires the creation of urban network models for each scenario. An Urban Network Model (UNM) is a representative model of the transportation and land use system within each scenario. We create one or more UNM for each scenario, where specific parameters such as walking and transfer time between modes are adjusted. For an explanation of each parameter, refer to "Parameters of the Urban Network Models" in Section 3.3 of the SM. Each UNM is constructed by connecting land use with the street and transportation networks (Bus Rapid Transit, Minibus taxi, Railway and Bus). Refer to Section 3.3 for a technical description of a UNM and each data source in Table 7 of the SM.

Measuring Accessibility

Network centrality measures are commonly employed to evaluate the importance of nodes in a graph, based on their spatial or topological position within the network (e.g., Sevtsuk and Mekonnen, 2012). Building on this concept, to measure accessibility, we apply a cumulative metric called *Neighbourhood Reach Centrality* (NRC). This calculates the number of places of employment that can be reached from each neighbourhood using Dijkstra's shortest path algorithm. Following this formalisation neighbourhoods are composed of agglomerations of vertices which fall within the official administrative boundary of each neighbourhood. We apply different time thresholds in our analysis: 15, 30, 45 and 60 minutes, meaning the total travel time for each trip cannot be more than the specified time. For a detailed description of NRC and associated equations, refer to the Methods section of the previous chapter or Nelson et al. (2025).

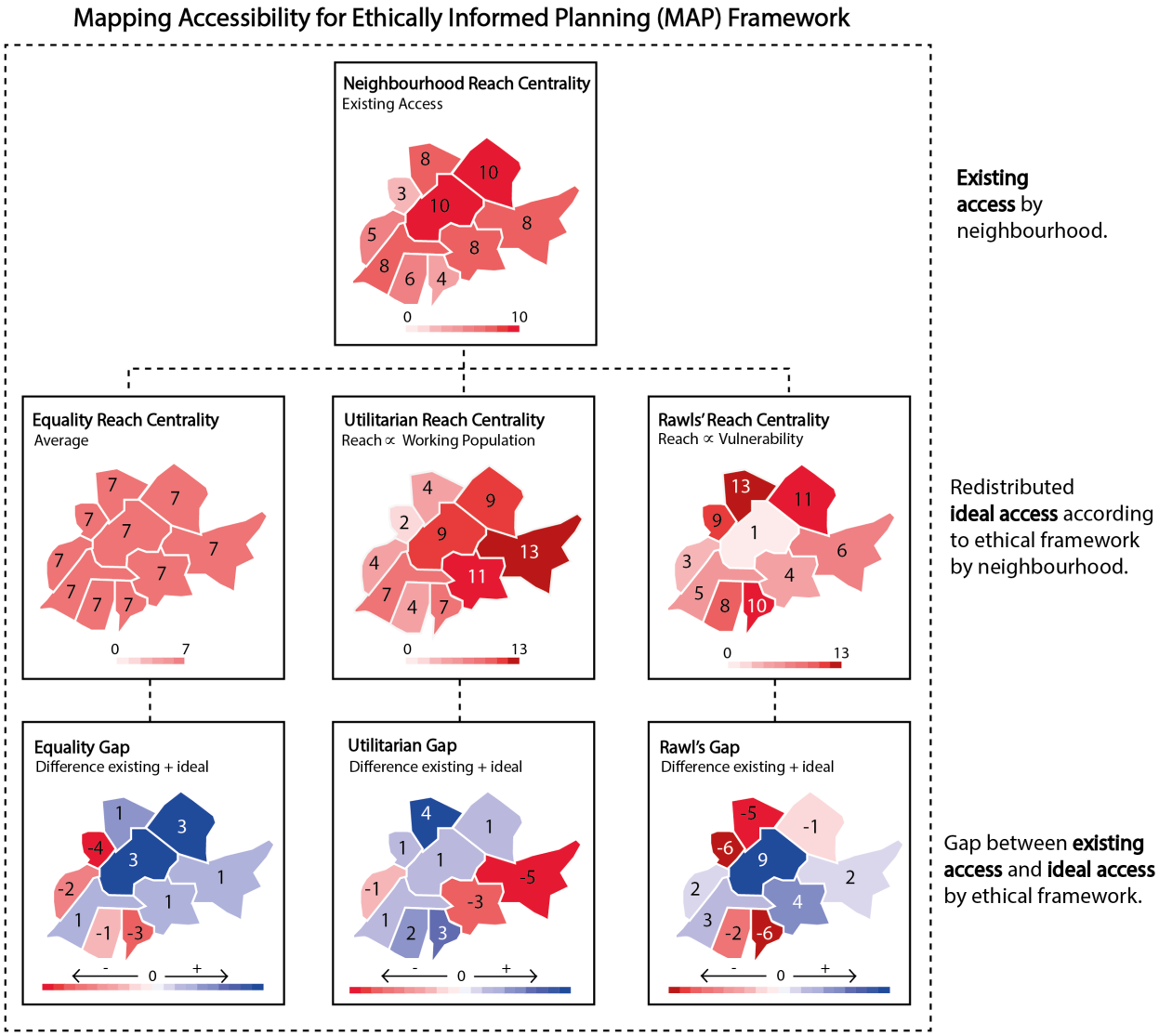


Figure 5.17: This figure illustrates the MAP framework. The first row illustrates a map of existing cumulative access for an urban area by neighbourhood. The second row illustrates the ideal access level for each neighbourhood in the urban area by ethical framework. The third row illustrates the difference between ideal and existing access, when a neighbourhood's gap is below 0 it does not meet the requirement for justice from that particular perspective.

It is important to acknowledge that measured accessibility serves as a proxy for actual perceived accessibility. Perceived accessibility is defined as the perceived potential to participate in spatially dispersed opportunities (Pot et al., 2021), in this case, places of employment. There is a mismatch between how accessibility is perceived and measured, as there is a range of barriers to accessibility which may not be fully represented through spatial models, as perceptions and individual capabilities differ from the measured built environment. Although we have captured some perceptions through changing variables in each of the models by scenario, such as walking time, we acknowledge that they are limited in capturing the diversity of perceptions which could and would exist across populations and neighbourhoods, serving only as a proxy.

Measuring Equity

Once accessibility has been calculated for each neighbourhood within each scenario, we apply three metrics which operationalise three alternative ethical principles to redistribute access based on each principle. They are *Equality Reach Centrality* (ERC), *Rawls' Reach Centrality* (RRC) and *Utilitarian Reach Centrality* (URC). For a technical explanation of the associated equations and calculations underlying these metrics, refer to the Methods section of the previous chapter or Nelson et al. (2025).

ERC is rooted in the principle of egalitarianism and thus assumes that all neighbourhoods should ideally possess equal access to available opportunities. Following this formalisation, for each scenario, the *Neighbourhood Reach Centrality* (NRC) is redistributed so that each neighbourhood is given an ideal access level equivalent to the average. As an illustration, if the total NRC of all the neighbourhoods for a particular scenario is 100 and there are 2 neighbourhoods in the system (A and B), each neighbourhood would be given 50 (100 divided by 2) as the ideal access. To assess deviations from this ideal and actual calculated access, *Equality Reach Gap* (ERG) is applied to each scenario which quantifies the difference between the actual reach centrality (NRC) and its corresponding egalitarian benchmark (ERC).

URC, inspired by utilitarian philosophy, which emphasises maximising benefit for the largest number of people (Bentham, 1907) assumes that a neighbourhood's access should be proportional to the ratio of working population that reside in that neighbourhood. Following this formalisation, for each scenario, the NRC is redistributed so that each neighbourhood is given an ideal access proportional to its working population (between 18 and 65). As an illustration, if the total NRC of all the neighbourhoods for a particular scenario is 100 and there are 2 neighbourhoods in the system (A and B) and Neighbourhood A has a working population of 150 and B of 50, Neighbourhood A would be given 75 and Neighbourhood B 25 as the ideal access. To assess deviations from this ideal and actual calculated access, *Utilitarian Reach Gap* (URG) is applied to each scenario which quantifies the difference between the actual reach centrality (NRC) and its corresponding Utilitarian benchmark (URC).

RRC draws from Rawlsian justice theory, which prioritises the well-being of the most disadvantaged groups (Fainstein, 2016:263). In operational terms, this perspective assumes that accessibility should be allocated in proportion to a neighbourhood's vulnerability level (Nelson et al., 2025). Following this formalisation, for each scenario, the NRC is redistributed to be proportional to a neighbourhood's calculated vulnerability score. To quantify vulnerability, we calculate a composite Vulnerability Score for each neighbourhood, based on the relative levels of the neighbourhood population's income, employment and education, derived from the South African National Census 2011 (Nelson et al., 2025). *Rawls' Reach Centrality* (RRC) is then obtained by adjusting each neighbourhood's reach (NRC) in proportion to its vulnerability score (Nelson et al., 2025). As an illustration, if the total NRC of all the neighbourhoods for a particular scenario is 100 and there are 2 neighbourhoods in the system (A and B), and Neighbourhood A has a vulnerability score of 0.6 and Neighbourhood B has 0.4, Neighbour-

hood A would be given 60 and Neighbourhood B 40 for ideal access. To assess deviations from this ideal and actual calculated access, *Rawls' Reach Gap* (RRG) is applied to each scenario to quantify the difference between the actual reach centrality (NRC) and its corresponding Rawlsian benchmark (RRC).

Overall the MAP framework allows for each of the ethical frameworks to be applied to each scenario and compared through maps. We normalise the results of each gap metric between -1 and 1, which allows for direct comparison between them. The normalisation process is as follows: $x_a^{(T)}$ represents the original reach value for neighbourhood a at a time threshold $T \in \{15, 30, 45, 60\}$. The $x^{\min}$ and $x^{\max}$ denote the minimum and maximum values across all selected columns and observations, defining the scaling factor as:

$$M = \max\left(\left|x^{\min}\right|, \left|x^{\max}\right|\right) \tag{5.10}$$

The normalised reach value $\tilde{x}_a^{(T)}$ is then calculated as:

$$\tilde{x}_a^{(T)} = \frac{x_a^{(T)}}{M} \tag{5.11}$$

This normalisation preserves the sign of the original values and ensures that zero remains unchanged, with all normalised values falling within the range $[-1, 1]$. The advantage of employing multiple ethical theories within one comparative framework, is it allows different issues to be highlighted at the neighbourhood scale. This could relate to deficiencies in access based on population size or vulnerability, with the overarching intention of stakeholders being able to engage and debate these issues further.

5.4 Results

The results are divided into five distinct, but interconnected sections. The first section presents the findings of our investigation into the transport policy landscape in the CoCT. The second and third sections enrich this understanding by shedding light on characteristics of accessibility and drivers of transportation development based on the thematic analysis of the transcripts. Building on the first three sections, the fourth section presents a description of four scenarios. The final section evaluates each scenario using the MAP framework.

5.4.1 Stakeholder and institutional analysis: misalignment between policy and operation of transport

The development and maintenance of transportation systems is shaped through mechanisms of institutional governance and policy (Jacobs, 2022). Understanding these mechanisms shines light on historical, as well as current factors which contribute to inequities in accessibility. Our analysis shows that spatial and transportation planning in South Africa sits within a wide policy landscape, enacted by all three levels of government (National, Provincial and Municipal), as shown in Figure 5.18. In reviewing key policy documents enacted across the three levels, clear visions of integrated transport and land use planning are espoused. According to the national Spatial Planning and Land Use Management Act (SPLUMA) *spatial justice* is one of the primary principles upon which all spatial planning in South Africa should be based, through "redressing past spatial imbalances through improved access to and use of land" (SPLUMA, 2013:19). Whereas local policy documents, such as the Comprehensive Integrated Transport Plan (CITP, 2023) outline a detailed vision for a fully multi-modal, integrated transport system to provide "all people with efficient access to a range of opportunities in a sustainable and dignified manner" (CITP, 2023:3).

Our analysis of the organisation of the transportation system reveals many structural and operational barriers. Each of the four main modes of public transport are operated by different stakeholders and subject to different levels of government influence (refer to Figure 5.18). The train system is managed and owned by the Passenger Rail Association of South Africa (PRASA), a state-owned entity with the National Department of Transport being the main shareholder and source of funding. Whereas, the majority of public bus services fall under the auspices of the private company, Golden Arrow Bus services (GABs). Their operations are fully independent, but they receive national subsidisation. The MyCiti Bus Rapid Transit (BRT) is directly operated and funded by the CoCT. Whereas the minibus taxi industry is composed of thousands of private operators, governed by regional taxi associations who receive operating route licences (ORL) from the provincial government granting them permission to operate on specific routes. Minibus taxis (taxis) initially developed informally as an illegal industry during Apartheid, when people of colour were not permitted to own businesses in urban areas. They arose to serve the real needs of the marginalised and under-serviced non-White urban population. Whilst they are legalised now, they are loosely regulated. As a result, the taxis are the only form of public transport that are not subsidised. As a counter balance, it is well known that they predominantly operate without paying tax and that the taxi associations charge fees to each operator for every ORL, which has led to a system of rivalry (Tosh-Mlambo, 2024:17). Furthermore, there is not only competition between individual operators, but also between the taxi industry and alternative modes, when at its height has led to acts of violence (Duba, 2023).

Whilst both national and local policy advocates for an integrated and fully multi-modal transportation system with the aim of providing accessibility to all citizens and redressing past spatial imbalances, there is high operational fragmentation. The decline in modal share of the railway signifies inefficient resource allocation and governance of this system (down 10% from 2013 according to the CITP, 2023). The Central Line, which is the line that serves the most disadvantaged areas, has not been fully operational since 2020. Whereas the rise of minibus taxi modal share reflects its resilience and capability in being able to respond to the needs of a rapidly growing population (up 10% from 2013 according to the CITP, 2023). Refer to Table 9 in the SM for a summary of key characteristics of each transport mode. Our analysis highlights a clear disconnect between visions for integrated transport espoused in policy and the fragmented operational functioning of transport.

5.4.2 Contextualising accessibility in Cape Town

The insights drawn from the stakeholder and institutional analysis serve as a foundation for the stakeholder engagement. One of the main prerequisites to developing the scenarios involved establishing perceptions of accessibility within the context of Cape Town based on the stakeholder engagement.

In reviewing the transcripts, one of the defining contextual characteristics which emerged in relation to perceptions of accessibility is the high level of socio-economic and spatial inequalities which exist across communities and regions in the CoCT, as illustrated by the quote in Figure a of Figure 5.19. This confirms that the vision of spatial justice, as envisioned in SPLUMA (2013), is far from being achieved. Certain operational factors, such as differences in levels of transportation services and economic opportunities, were highlighted. Private car ownership is associated with those of high socio-economic status and public transport, especially the taxis, reserved for the urban poor. For example, Figure b of Figure 5.19 describes the complex and long journey the domestic worker (cleaner) of one of the stakeholders has to take in order to get to work.

Important social characteristics were emphasised in the interviews, such as inequalities in knowledge dissemination on the transportation systems. Figure c of Figure 5.19 illustrates how perceptions of car ownership as being the predominant and preferred mode of transport shape the belief that accessibility issues can be directly addressed through expanding car lanes. Language barriers are another issue that emphasise people's perceptions of accessibility. For example, a taxi driver may speak one of

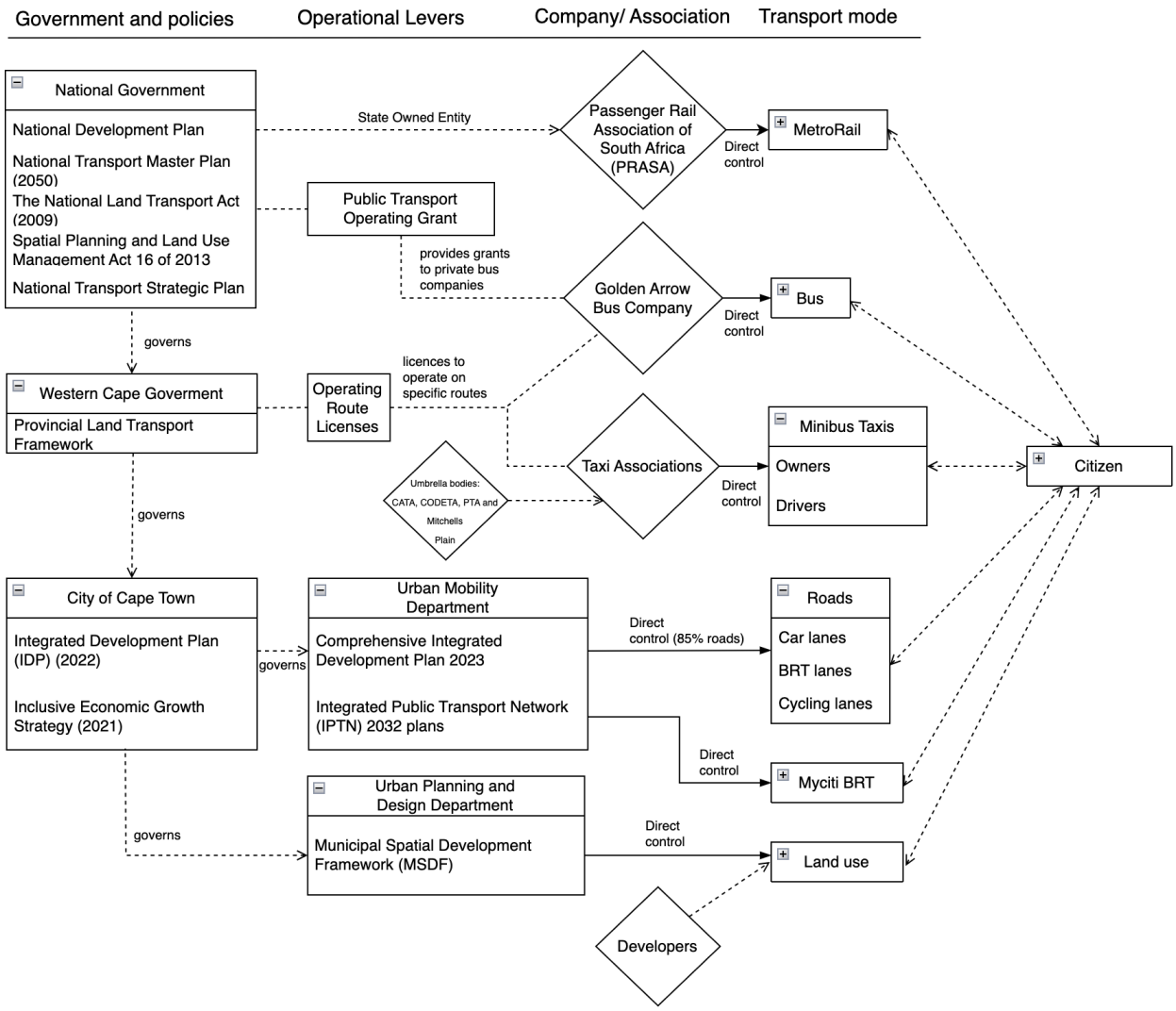


Figure 5.18: This figure showcases a diagrammatic representation of the urban and transport planning landscape in the CoCT. It emphasises the fragmented nature of the transportation governance landscape, with each transport mode governed by a different level of government, private company or association/s.

South Africa's 12 official languages and a user, a different language (illustrated by the quote in Figure a of Figure 5.20) which represents a barrier to making use of this system. There was general consensus that safety is a primary concern, especially when walking and cycling. A workshop participant told us that even though they live in a neighbourhood which is considered to be quite central, it is not well serviced by the bus and they are unable to walk into the City due to safety concerns (refer to Figure b of Figure 5.20). Community agency to effect change was also a central issue. Another participant highlighted how operators might strike, garnering media attention, but communities rarely have a platform to voice their concerns (refer to Figure c of Figure 5.20).

Many of the participants' concerns were underscored by the high levels of social segregation in the city. A third participant, spoke about long commuting times, suggesting that "15 minute city ideas" (see, Moreno et al., 2021) need to be adopted to support better access to opportunity. Another recurring theme, which differs significantly from a typical city in the global North, is the disconnect between so-called, "formal" and "informal" services. A fourth participant, pointed out, that of all the forms of public transport, the taxis are the only system which operate without subsidy. They suggested that if perhaps the taxis were subsidised this could incentivise more respect for the rules of the road, improving safety levels.

To structure the multitude of factors which influence perceptions of accessibility, as discussed in the previous two paragraphs, we summarise them in the conceptual framework shown in Figure 5.21. It shows that accessibility in the CoCT is underpinned by four foundational rings. The innermost ring being the *Social and community foundation* which refers to perceptions of safety, collective knowledge of the city and transport systems and a community's agency to influence the development of transportation systems. The second ring is the *Land-use foundation*, which focuses on the decentralisation and distribution of land use, the availability of affordable housing in proximity to services and the integration of informal services into the broader economy. The third ring is the *Transport foundation*, which consists of integrated travel (the degree to which transport modes are integrated, transportation networks, timetables, transfer times and fare systems, notably including the minibus taxis), efficient travel (how responsive, fast, viable it is to travel) and affordable travel (the monetary cost associated with travel, which is very high for the urban poor). The final ring is the *institutional and governance foundation* which refers to the level of institutional coordination between different entities, trust and ability to cohesively plan, develop and implement transport services. Concepts of accessibility have been developed over many years, the framework developed here builds on this long body of research. It adds to it by shedding light on the specific challenges related to accessibility facing a city in the global South by incorporating perceptions from stakeholder in Cape Town.

5.4.3 Driving forces of urban development

The conceptual framework shown in Figure 5.21 sheds light on the contextual factors that would be required to achieve access in the CoCT. In order to establish the scenarios, it is necessary to build on these insights to determine key drivers of urban development. Through the thematic analysis of the transcripts, we identified 10 key drivers which are visualised and explained in Figure 5.22, as well as Section 3.3 of the SM.

5.4.4 Scenarios

We organise the systemic understanding of accessibility developed through the analysis of institutional policy landscape, factors which influence accessibility and the driving forces to develop coherent scenarios. Each of the driving forces, in each scenario exist within a specific state (low to high) and come together in a specific way to form a coherent narrative (refer to Table 6 in the SM). This was based on the understandings of potential scenarios derived from the transcripts and subsequent thematic analysis. Each scenario was checked for consistency through additional interviews.

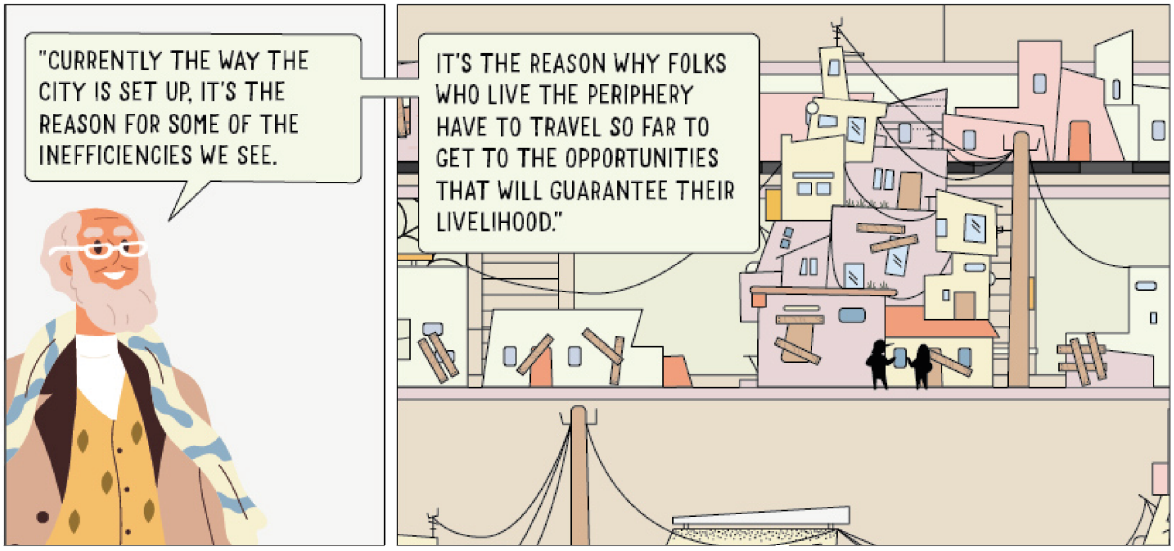


Figure a

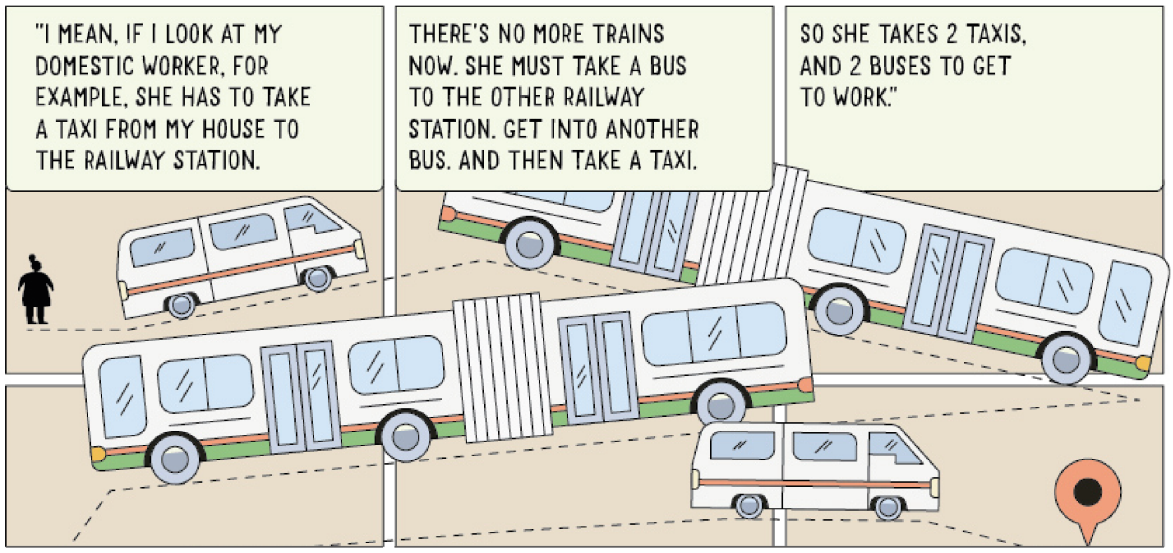


Figure b

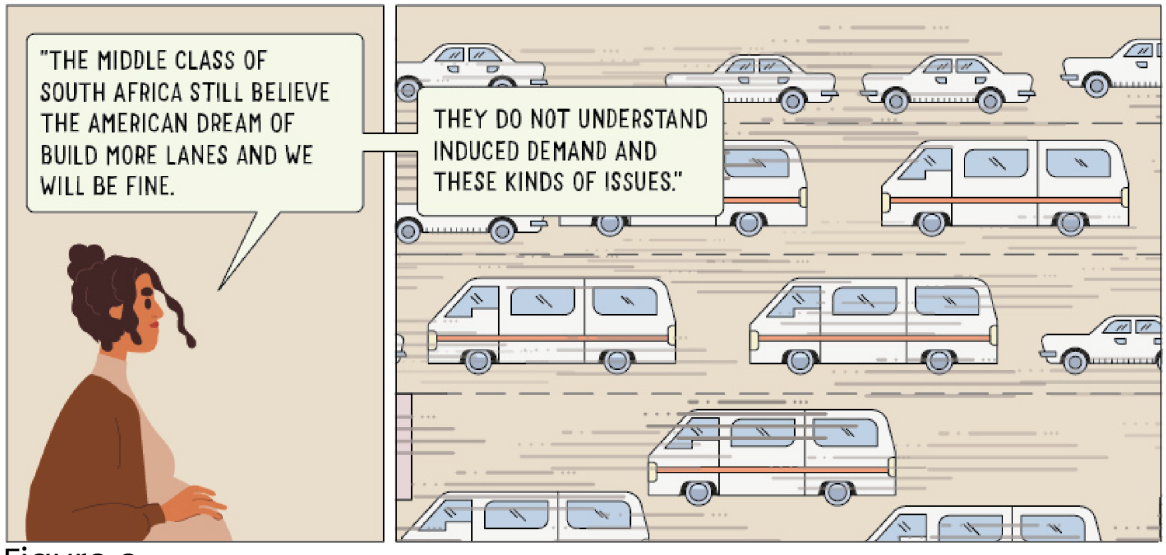


Figure c

Figure 5.19: This figure presents direct quotes from workshop participants illustrating different concerns, such as *safety*, *community agency* and *information*. Illustration by Agata Smok.

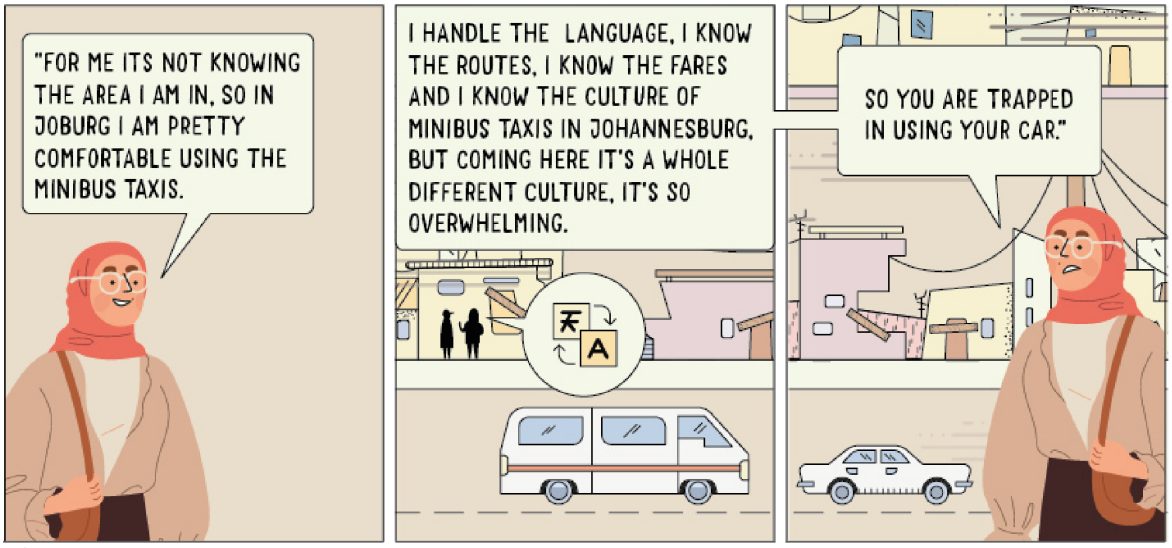


Figure a

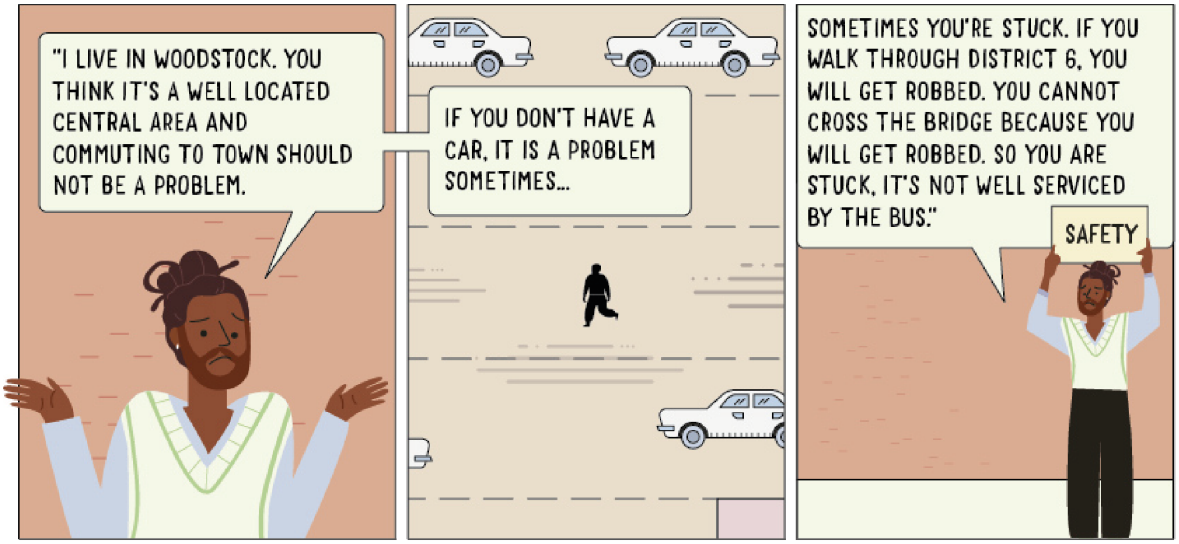


Figure b

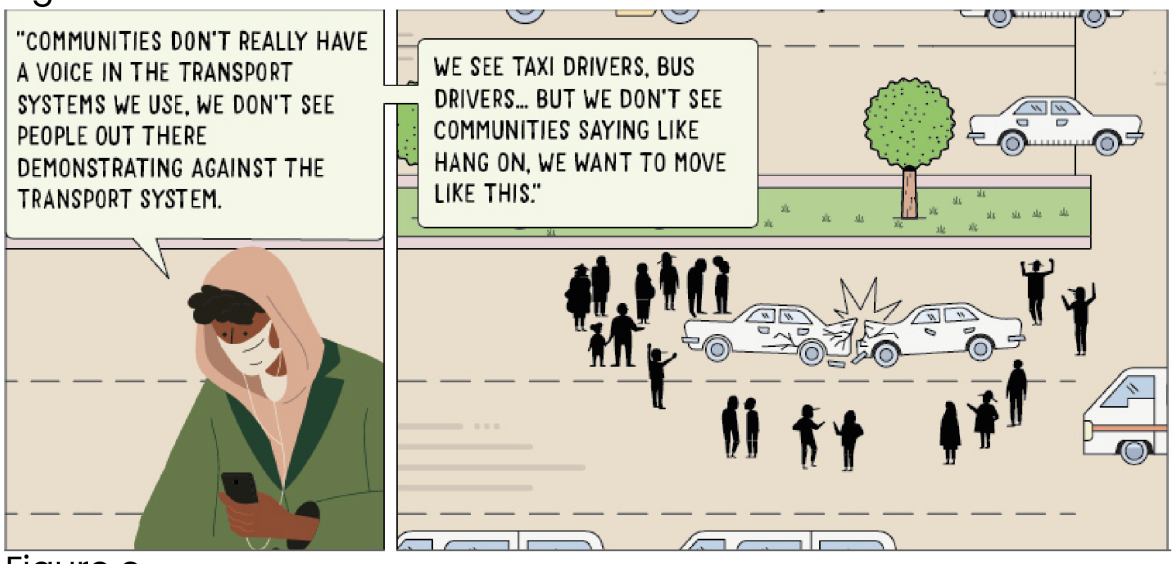


Figure c

Figure 5.20: This figure presents direct quotes from the stakeholder interviews illustrating different concerns, such as *spatial organisation* and *education*. Illustration by Agata Smok.

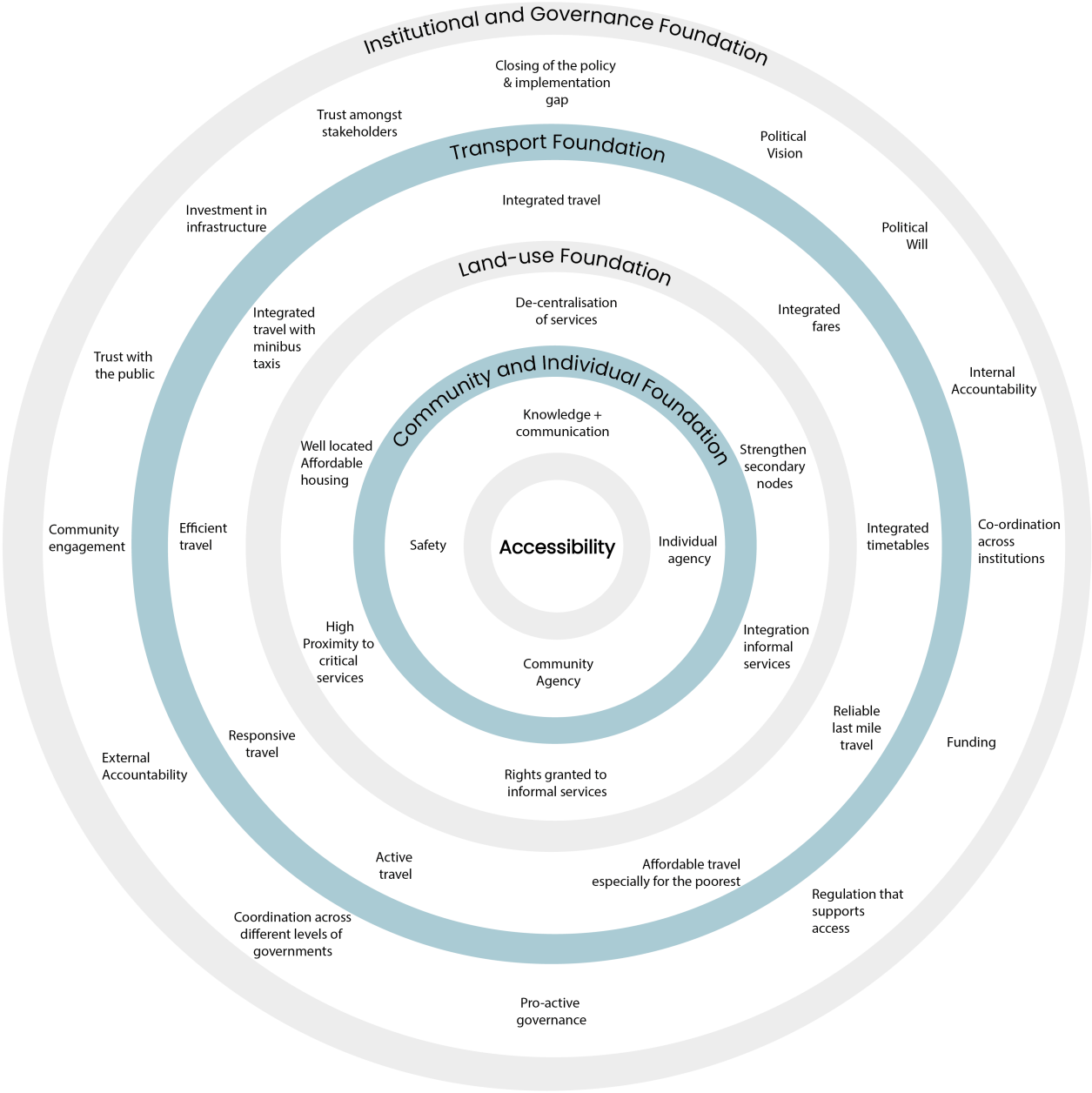


Figure 5.21: This figure presents an enriched formalisation for accessibility within the CoCT. This formalisation is underpinned by four foundational rings and also emphasises issues which are unique to a city in a global majority context, such as the integration of "informal" services.

1.
Strength of institutional relationships

The relationships between institutional entities have deep consequences for the operation & regulation of transport. This was especially cited in relation to the historical divide between the taxi industry and government.

2.
Levels of multi-modal integration

Levels of multi-modal integration refer to the degree of co-ordination across organisational, operational and physical spheres of alternative transport modes. This was especially cited in relation to different fare systems, transfer times and organisational factions and rivalry.

3.
Political will & institutional capacity

The ability to implement transport policy is constrained by the visions of politicians and the institutional capacities within government to co-ordinate, implement, manage and design intervention.

4.
Trust and Accountability

Trust and accountability between the stakeholders (such as government and minibus taxis), but also the general public is key. The interviewed Ward Counsellor highlighted the need for a more professional, holistic approach to political oversight to improve accountability through a more informed public.

5.
Nature of the economy

The strength of the economy was cited as a key uncertainty, as it influences grants, subsidies, investment in infrastructure and the ability for people to pay for transport. Another key concern was how formal/informal the economy is.

6.
Railway functioning

The majority of participants believed the railway should be the backbone of public transport due to its speed and capacity to carry so many passengers. However, it is vulnerable to mismanagement, insufficient funding and vandalism.

7.
Prioritisation of active travel

Active travel speaks to non-motorised forms of transport, such as cycling and walking. Prioritising active travel would involve travel behaviour change and community advocacy to push government to prioritise infrastructures that support walking and cycling.

8.
Safety of people and infrastructures

The degree to which a person feels unsafe will influence their travel behaviour - likelihood to walk, cycle or even use public transport. Furthermore, safety of infrastructure against vandalism affects its ability to function efficiently and attract investment.

9.
Community agency

Community agency refers to the ability for communities to organise, take action, and effect change to address their own transportation needs through governance, policy and operation.

10.
Push towards carbon neutrality

This refers to the receptiveness of society to change behaviour and government to implement policies that support carbon neutrality. This could involve supporting modes of transport that are less carbon intensive & transforming existing fleets.

Figure 5.22: This figure presents the 10 main driving forces of urban and transportation development identified through the thematic analysis of the stakeholder interview transcripts.

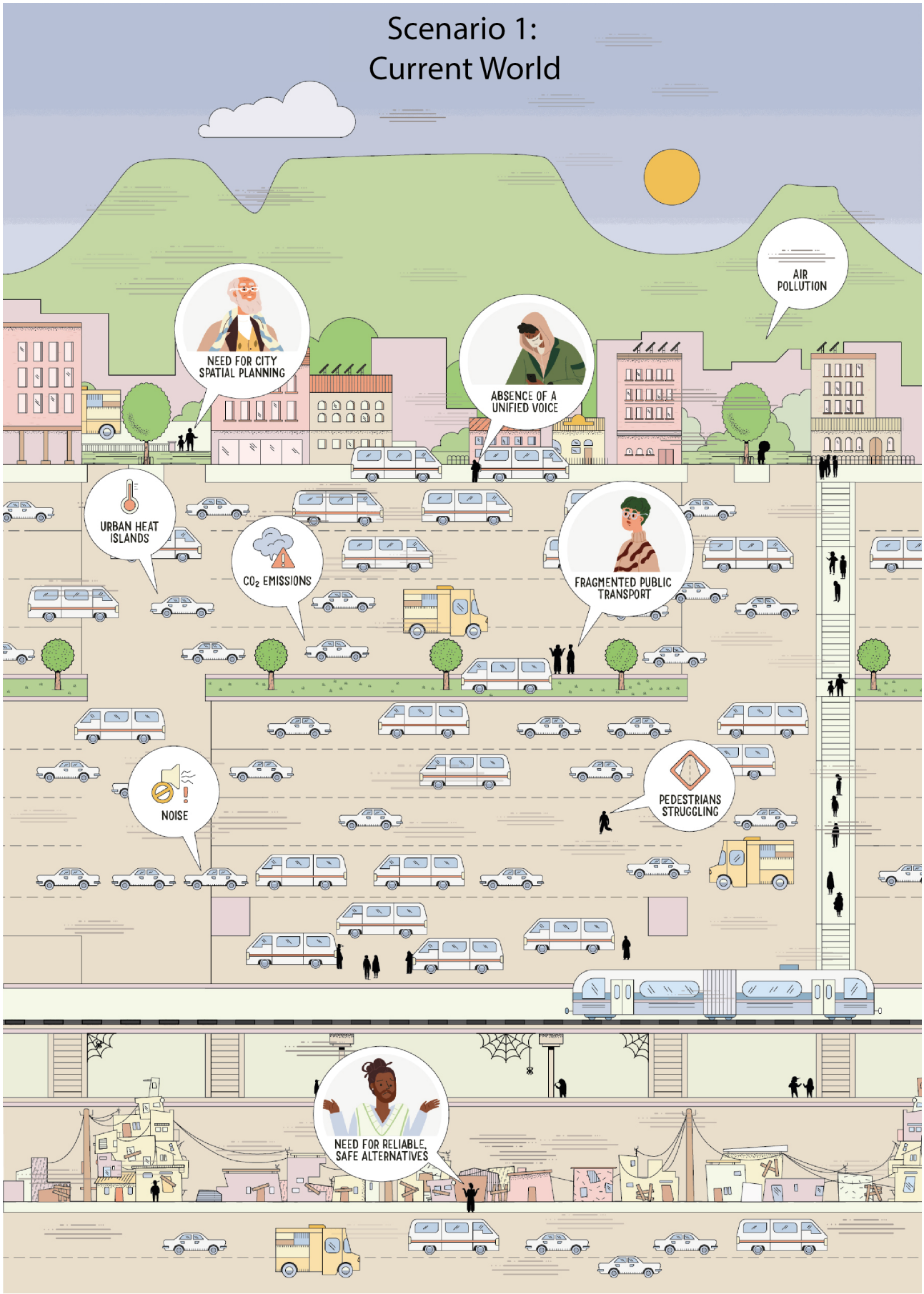


Figure 5.23: This figure illustrates a visual depiction of the *Current* Scenario, as described in the main text. Illustration by Agata Smok.

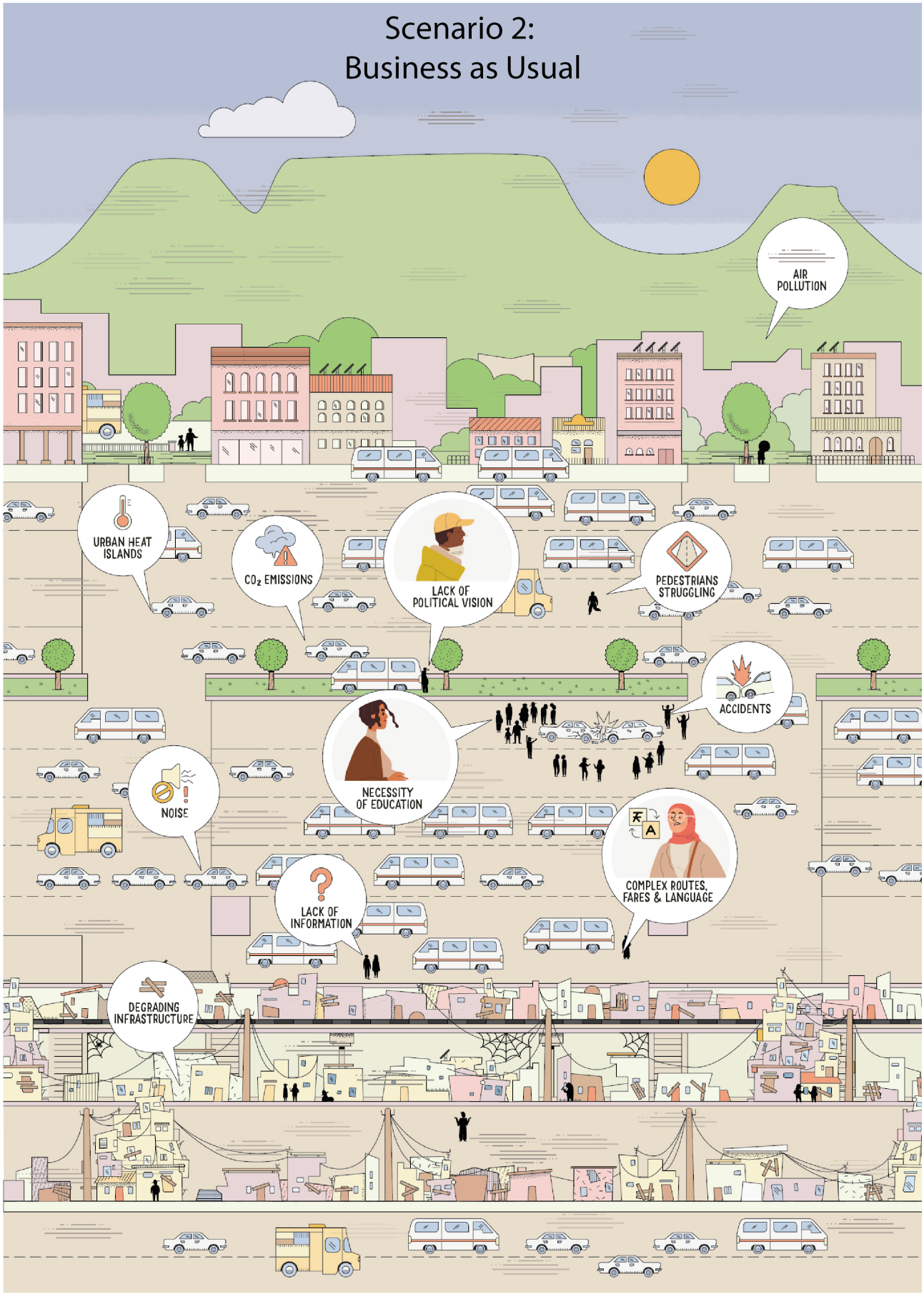


Figure 5.24: This figure illustrates a visual depiction of the *Business as Usual* Scenario, as described in the main text. Illustration by Agata Smok.

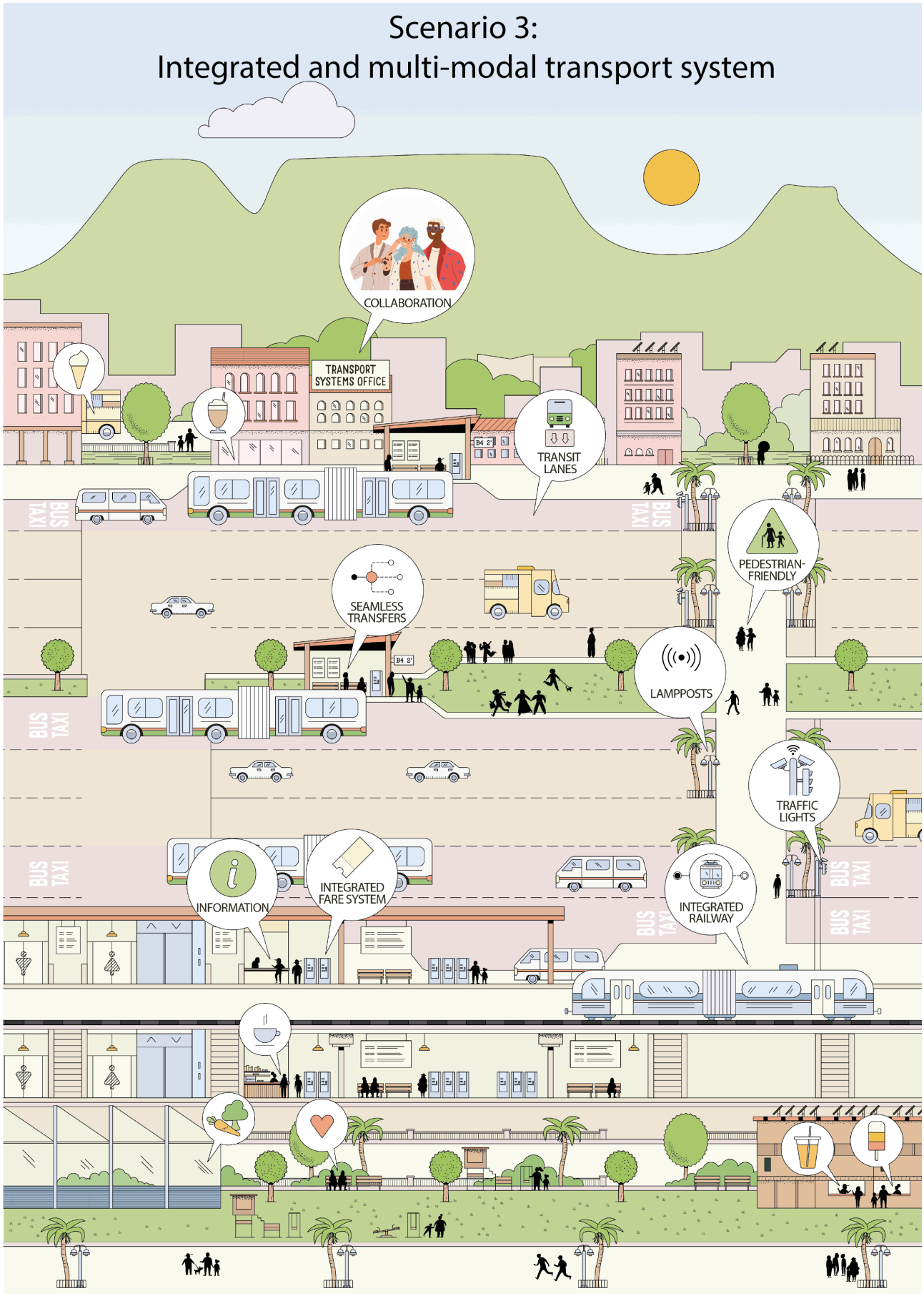


Figure 5.25: This figure illustrates a visual depiction of the *Integration* Scenario, as described in the main text. Illustration by Agata Smok.

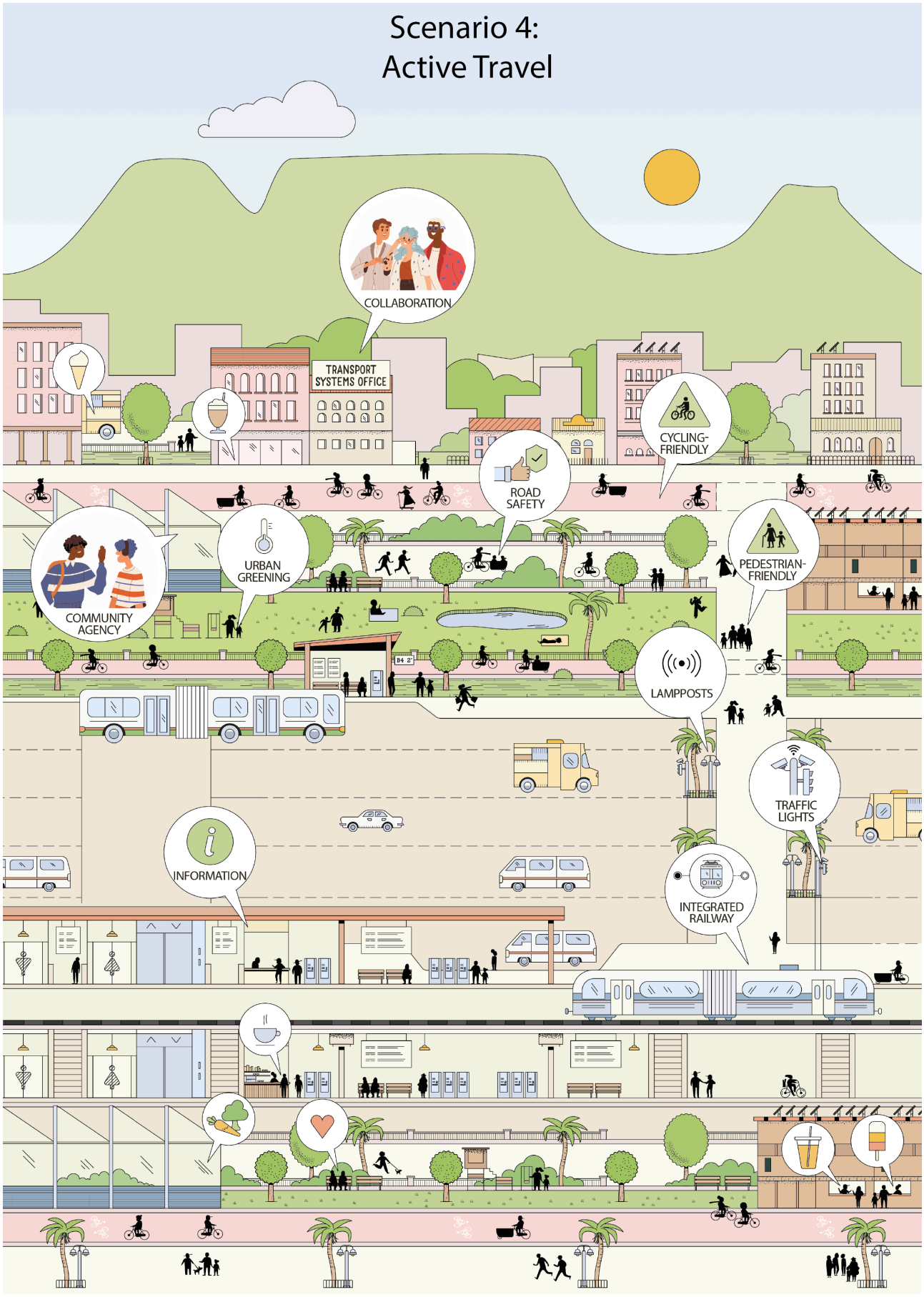


Figure 5.26: This figure illustrates a visual depiction of the *Active Travel* Scenario, as described in the main text. Illustration by Agata Smok.

Current scenario

The current transportation landscape is characterised by a lack of integration between different modes of transport, with parts of the railway system being non-operational, as can be seen in the Current scenario depiction in Figure 5.23. The institutional framework is fragmented, marked by a lack of political will and vision to implement effective policies. There is low trust between stakeholders, including local and national governments, which have differing objectives. This is especially evident in the strained relationship between the government and the minibus taxi industry, which has historically been marginalised and operates under a complex, competitive system. Operating route licences are sold at high prices within the industry, benefitting a select few and creating internal conflict. Despite being a critical mode of transport for many, the taxi industry remains under-supported and the poorest in society spend the largest share of their income on public transport (roughly 40% according to the CITP, 2023). Public transport is not particularly safe, both from the perceptions of users and security of infrastructure perspectives. Political leaders are hesitant to prioritise public transport, partly to avoid alienating influential groups like the middle class who may not be fully informed when it comes to issues such as induced demand, which refers to a phenomenon where car usage is induced through road infrastructure. There is a disconnect between political decision-making and community needs, with politicians focused more on maintaining power than addressing transportation issues. Local governments are forced to plan independently due to a lack of coordination from the national government, leading to inconsistent oversight and poor maintenance of services. While there is an integrated transport plan, it has not been effectively translated into actions that the public or politicians can rally behind, resulting in a reactive political landscape and underperformance of the transport system.

Business as Usual scenario

A "Business as Usual" scenario represents a continuation of the existing trends without significant intervention or reform. In this situation, the fragmentation between different modes of transport persists, with no integrated system in place, making it difficult for commuters to transition seamlessly between transport modes, as can be seen in the Business as Usual depiction in Figure 5.24. The decline of the railway system continues, with no efforts to restore or expand services, leaving many areas under-serviced and placing more pressure on other forms of transport, particularly the minibus taxi industry. Political will to address these issues diminishes further, with even less attention given to public transport reform. Trust between stakeholders, including government bodies and the taxi industry, remains low, with competing objectives and a lack of meaningful collaboration. Non-motorised transport, such as walking and cycling, continues to be neglected in urban planning and infrastructure development, further entrenching car dependency and exacerbating traffic congestion. Funding remains inadequate, with subsidies for public transport falling further behind inflation, leaving systems underfunded and unable to meet the growing demand. Without sufficient financial support, both the public transport network and the infrastructure needed to support it, such as roads, stations, and pedestrian walkways, deteriorate. The continuation of these trends results in a deepening crisis, where mobility options for the city's residents, particularly the most vulnerable, become increasingly limited, inefficient and unsafe.

Integrated scenario

An "Integration" scenario would require a socio-technical transformation of Cape Town's transportation system from a fragmented to a fully multi-modal network that seamlessly connects all modes of travel, as can be seen in the Integration depiction in Figure 5.25. This involves not only technical and operational changes but also a more collaborative approach across different levels of government and greater inclusion of community voices in decision-making. An integrated fare system using a

single payment method and synchronised timetables make transfers between different modes more predictable, with reduced waiting times and smoother connections. The result is a more user-friendly and efficient experience for commuters. There is a high level of trust and coordination between transport operators, including the taxi industry, GABs, and the Metrorail which ensures that all modes work optimally together. Priority lanes and traffic signalling would be implemented for key transport services, like taxis and GABs, enabling them to bypass congestion and offer faster, more reliable travel times. Crucially, different levels of government, from local to national, would adopt an institutionally integrated approach, working together under a unified vision for urban mobility. This coordinated governance ensures consistency in policies, planning, and funding, resulting in a more coherent and well-maintained transportation network. Moreover, community agency is woven into decision-making processes, ensuring that transport solutions reflect the needs and priorities of local residents. By involving communities in planning and oversight, the system is more responsive to the real-world challenges people face daily. Overall, this integration enables a transportation system that is efficient, reliable, and accessible, encouraging more people to opt for public transport over private cars.

Active Travel scenario

An "Active Travel" scenario would require a shift in focus towards promoting active modes of transportation, such as walking and cycling, as central components of the urban mobility system. The emphasis is on sustainable, low-carbon transportation that prioritises health, safety, and environmental responsibility, as can be seen in the Active Travel depiction in Figure 5.26. The City invests heavily in the walkability and cyclability of its streets, redesigning urban spaces to make walking and cycling not only viable but highly attractive options. Streets are widened for pedestrians, dedicated cycling lanes are created, and infrastructure such as safe crossings, bike-sharing stations, and well-lit walkways is developed to support these modes. The emphasis on active travel aligns with Cape Town's push towards carbon neutrality, reducing reliance on motor vehicles and decreasing overall emissions. Safety is paramount with streets and public spaces being designed to ensure the safety of cyclists and pedestrians, with traffic calming measures, secure bike parking and policing. Community agency plays a significant role in this vision, local communities are actively involved in decision-making processes around the design and use of urban spaces. This approach ensures that transportation solutions are responsive to the specific needs of neighbourhoods, creating a sense of ownership and trust among residents. While active travel is at the forefront, rail is also given preference as the backbone of the public transport system. Investment in the rail network is prioritised, with improvements in service frequency, reliability, and safety. Rail becomes a key part of the low-carbon transportation strategy, serving as a complementary option to walking and cycling for longer distances. There are high levels of trust and accountability among stakeholders. Government institutions, transport operators, and local communities work closely together, with transparent policies and clear lines of responsibility. The system is designed to be inclusive, safe, and efficient, creating a more resilient urban mobility network that supports environmental goals, enhances community well-being, and provides viable alternatives to car dependency.

5.4.5 Equity of accessibility

An Urban Network Model (UNM) is created for each scenario. This results in one UNM for the Current Scenario and one UNM for the Business as Usual Scenario. For each of the Active Travel and Integration Scenarios we created two UNMs. This first UNM of the Active Travel Scenario prioritses walking, referred to as *Active Walking*. The second UNM prioritises cycling, referred to as *Active Cycling*. The first UNM of the Integration Scenario integrates all the travel modes with minimal transfer times, referred to as *Integration*. The second UNM of the Integration Scenario, represents a situation where all the modes are integrated, but gives the buses and taxis priority lanes thus reducing their overall trip time, referred to as *Integration Priority Lanes*. Each scenario represents a different combination of factors, such as operating railway infrastructure, transfer times between modes, av-

erage walking/cycling time allowed per trip. Each model allows us to compare potential outcomes, offering insights into how the conditions of each scenario might improve or hinder access to jobs. For a summary of the UNM parameters of each scenario, refer to Table 8 in the SM.

From an *Equality perspective* at 15 minutes the scenario which possesses the highest percentage of neighbourhoods which meet the requirement for justice is the *Active Cycling* scenario at 39% followed by the *Current* scenario at 32%. Whereas at 60 minutes the highest percentage of neighbourhoods which meet the requirement for justice is the *Integration Priority Lanes* scenario with 58%, followed by the *Active Cycling* scenario at 55% of neighbourhoods (refer to the first column of Figure 5.27).

From a *Utilitarian perspective* at 15 minutes the 'scenario which possesses the highest percentage of neighbourhoods which meet the requirement for justice is the *Active Cycling* scenario at 69% followed by *Integration Priority Lanes* at 63%. At 60 minutes the *Active Cycling* scenario possesses the highest percentage of neighbourhoods which meet the requirement for justice at 74%, followed by *Active Walking* at 69% (refer to the second column of Figure in 5.27).

From a *Rawlsian perspective* at 15 minutes the possible world which possesses the highest percentage of neighbourhoods which meet the requirement for justice is the *Active Cycling* scenario at 43% followed by the *Current* scenario at 31%. At 60 minutes the *Integration Priority Lanes* scenario possesses the highest percentage of neighbourhoods which meet the requirements for justice at 59% followed by *Active Cycling* at 54% (refer to the third column of Figure 5.27).

The implications of these results will be explored further within the Discussion.

5.5 Discussion

5.5.1 Accessibility based planning

Transportation and urban planning is a complex subsystem of society which has traditionally been based on a "predict and provide planning approach" (Lyons et al., 2018; Cooke et al., 2019). In practice, transportation planning has relied on optimisation engineering techniques to find the optimal solution for predicted future demand. Critically this approach ignores uncertainties and effects of latent demand, which represent the travel needs or desires that people have but are unable to fulfil due to constraints such as traffic congestion, lack of public transportation, or poor connectivity.

In contrast, accessibility-based planning emphasises people's ability to reach essential destinations, such as employment opportunities, which is the focus of this study. While this approach has gained traction in academic research and in assessing the impacts of existing transport infrastructure (Silva et al., 2017), it has been less commonly applied in forward-looking planning processes. This work bridges scenario-based planning with accessibility-focused transport research. Shifting planning practice toward accessibility involves a wide range of changes across multiple levels - technological, institutional, and cultural. While much attention is often given to the effect of new technologies and infrastructure in changing planning practice (Geels, 2018; Cooke et al., 2019), this study highlights that many drivers of accessibility are embedded in institutional capacities, urban governance, quality of relationships, funding, political vision and will. Furthermore, particularly in this setting, the strength of relations between the so-called "formal" and "informal" sectors of the economy is an important factor. A move towards accessibility would require a revision of the current regulations, policy instruments and relationships which mediate the interaction between these sectors, particularly in relation to the minibus taxis.

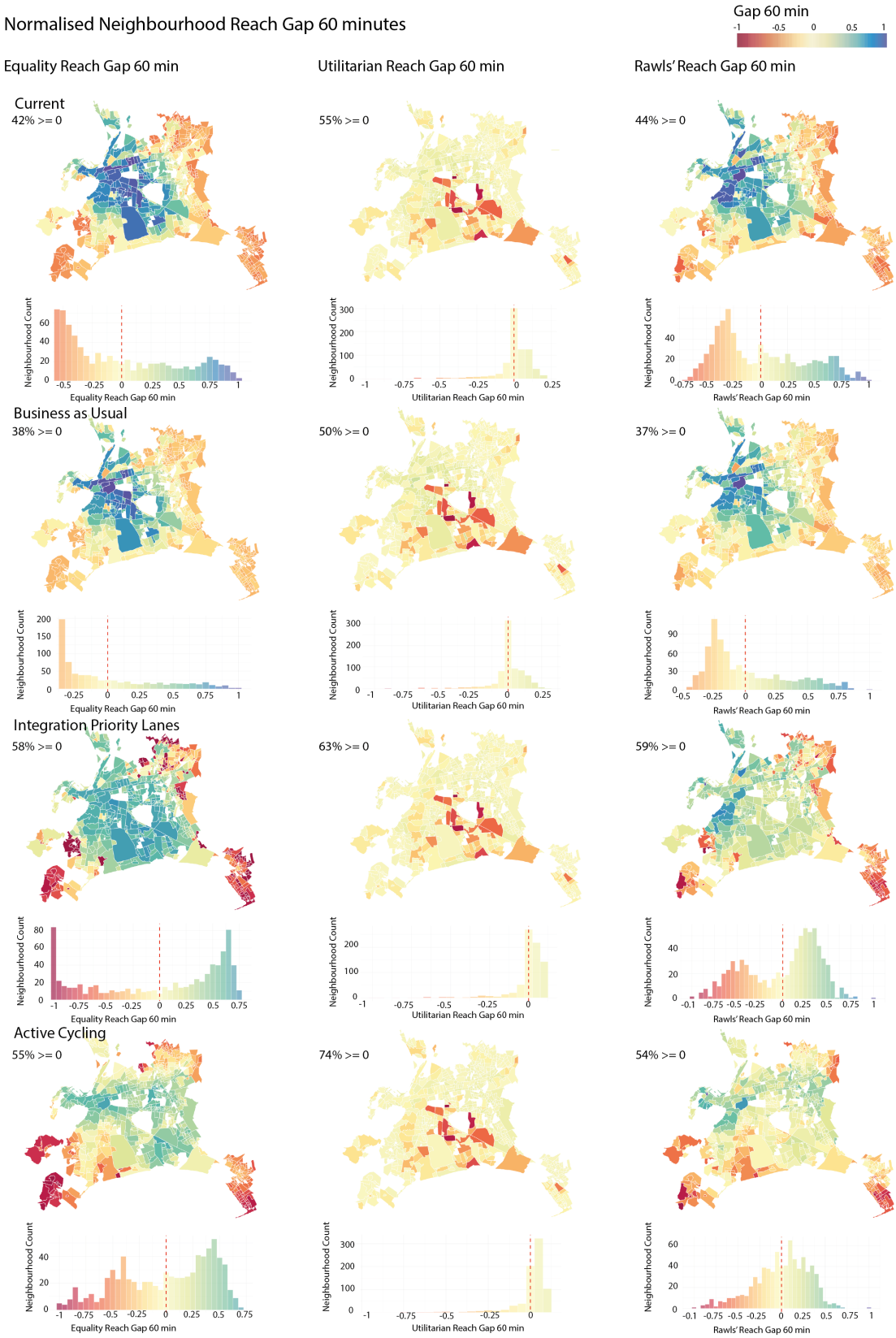


Figure 5.27: This figure shows the distribution of the gap metrics from each ethical perspective at 60 minutes for the Current, Business as Usual, Integration Priority Lanes and Active Cycling Scenarios. The distributions are normalised to be between -1 and 1. If a neighbourhood has a positive gap or gap equal to 0, it meets the requirement, if it is below 0 it does not.

5.5.2 Equity of Access Scenario insights

According to the equity evaluations, the *Business as Usual* scenario suggests that if existing trends continue, inequities will widen. Market-based strategies for urban development prioritise profit-making over social good and thus the development path with the least risk, leading to the reinforcement of old patterns of urban development. Moving away from current trends of development, would require coordinated and proactive governance to drive change. According to the analysis, from both Equality and Rawlsian perspectives, the ideal scenarios would include a combination of the *Active Cycling* and the *Integration Priority Lanes* scenarios. From a Utilitarian perspective, implementing only the *Active Cycling* scenario would be sufficient as it reveals the best results across all time thresholds. An important finding is that even if the transfer times were reduced to a minimum between all modes, the *Active Cycling* would still lead to more equitable outcomes from all ethical perspectives. The primary factor, thus, which placed the *Integration Priority Lanes* scenario as the most equitable outcome, from certain scales and perspectives, was the reduction in taxi and bus travel times. This suggests that providing priority lanes and signalling to reduce travel times on these modes could have a real impact. The quantitative evaluation is a useful tool to visualise and explore the varying impacts of accessibility for equity, but if applied in practice would need to be debated amongst the stakeholders. From all the perspectives, but particularly from a Utilitarian perspective, land use deficiencies are emphasised. This is most salient in historically disadvantaged neighbourhoods in the South-east regions of Cape Town, refer to the second column in Figure 5.27. This highlights an important point: transport is not the only solution, but land use and affordable housing close to places of employment also have a role to play.

5.5.3 Equity of future development

Equity of access is based on the idea that justice should be concerned with equality of opportunity. In our work, equality of opportunity translates to seeking justice through providing a job opportunity mediated by the provision of a transport system. The institutional analysis revealed that there is a disconnect between policy and operation. Every stakeholder has a different viewpoint, and thus it is imperative to involve less historically represented actors, such as those who attended the in-person workshop. As shown by the different quantitative equity evaluations, there are physical improvements which can be made. However, in order to achieve these, the underlying social and institutional issues, such as trust, institutional coordination, education and community knowledge need to be addressed.

The evidence suggests that a focus on cycling has significant potential to reduce inequities. In reality this would involve a number of changes. Firstly, in relation to infrastructure, cycling lanes and bike parking would need to be developed. Secondly, behavioural change in travel patterns, would need to be encouraged through advertising campaigns, education and regulation. For example, in Mexico City, car usage is regulated through only certain car number plates being allowed to drive on highways on certain days of the week and certain roads being completely closed for cycling only on a Sunday. Thirdly, open governance and relationship building across all sectors of transportation would be necessary. Cycling would be beneficial for all as it could be used for first and last mile commuting, making public transport ultimately more attractive. Finally, there would be opportunities for new businesses to emerge from bike sharing, to renting, parking and storage - the private sector has a role to play.

5.6 Conclusion

This study has drawn on both accessibility and transport scenario literature to incorporate explicit equity concerns within scenario planning for future development. Equity is a contested notion, and that is a primary motivation for involving diverse stakeholders and community organisations to support collective decision-making. The equity insights presented here are not meant to be deterministic, but

can be used in a generative way to facilitate decision-making and coordination processes. The results also highlight the complexity of moving from a market-oriented, demand-driven mode of planning to co-creation and accessibility focused transportation planning. Future research could focus on qualitative assessments of the scenarios with perceptions of accessibility, in addition to the quantitative insights presented. Furthermore, we advocate for a research agenda that focuses on bridging the gap between research and practice, so that these insights are applied for wider societal benefit.


SHOWCASE
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Conclusion

This chapter provides a summary of how the research questions were answered. It then reflects on the wider implications and limitations of this work for science, society and future research.

"The City is what it is because our citizens are what they are."

– Plato

The way cities are organised impacts the daily lives of urban residents. This research is centred on understanding what drives unequal cities by developing an approach that integrates critical theory with local, empirically grounded insights to inform actionable pathways for policy and planning. It stems from a genuine critical concern for inequalities in cities, alongside other political, academic and societal actors, in response to the intensification of injustices around the world concerning housing (Madden, 2025), land (Red Cross Netherlands[17], 2025), transport (Tori et al., 2023) and urban governance related crises (European Commission[18], 2023). For the concluding chapter of this dissertation, I first provide a brief summary of how each research question was addressed and then reflect on the deeper contributions of this work for science, society, avenues for future research and limitations.

6.1 Answering the research questions

Based on the research gaps identified in Chapter 1, the research questions are formulated and answered as follows.

R1 & 2: What underlying perspectives govern the geospatial analysis of urban inequalities, and how can the perspectives be linked to create an overarching theoretical framework to enhance understanding of the structural urban inequalities?

Chapter 2 focused on developing an understanding of how inequalities are reproduced in cities, beyond conventional economic definitions (Yap et al., 2021:7). Recent advancements in geospatial analysis have highlighted the multi-dimensional nature of urban inequalities, sparking debates across various thematic areas. However, the selection of metrics, variables, and theoretical approaches in geographical analyses remains inconsistent, making comparative assessments difficult. Through a systematic literature review, I identify three predominant research perspectives and their associated methods: (1) geospatial analysis of inequalities in accessibility to resources, (2) the distribution of resources across different spatial and temporal scales, and (3) policy and stakeholder perspectives, which emphasise the role of policies on specific stakeholders within particular institutional contexts.

To address the second research question, I integrate these perspectives with complexity theory (Manson and O'Sullivan, 2007; Batty, 2013; Zhong et al., 2014; Anderson and Dragićević, 2020). To engage with the complex system that reproduces inequalities, I conceptualise cities as consisting of interrelated Social, Spatial, Temporal, and Critical Infrastructure subsystems (see Figure 6.28). By applying complex systems thinking to geospatial perspectives, the emphasis is on the interactions between social systems (governance, private, community, individual) and critical infrastructure systems (ecological, urban, material and energy, digital) in cities. For example, while governance networks are often considered, they are usually central only to policy and stakeholder perspectives, which focus on the interaction between government structures and specific socio-economic groups. In contrast, accessibility perspectives primarily examine the interaction between urban infrastructure and individual or community characteristics, such as the relationship between certain population groups and employment opportunities.

This framework, as illustrated in Figure 6.28 highlights the primary mechanisms driving urban inequalities. Within the social subsystem, governance, policies, the private sector, and community action shape decisions about the development and management of critical infrastructure. In turn, critical infrastructure influences social structures by shaping access to and distribution of resources. These interdependent feedback loops create and reinforce urban inequalities, which evolves out of these interactions over space and time.

[17] https://www.rodekruis.nl/nieuwsbericht/de-7-crises-die-de-wereld-niet-kan-negeren-in-2023/
[18] https://civil-protection-humanitarian-aid.ec.europa.eu/what/humanitarian-aid/urban-crises$_en$

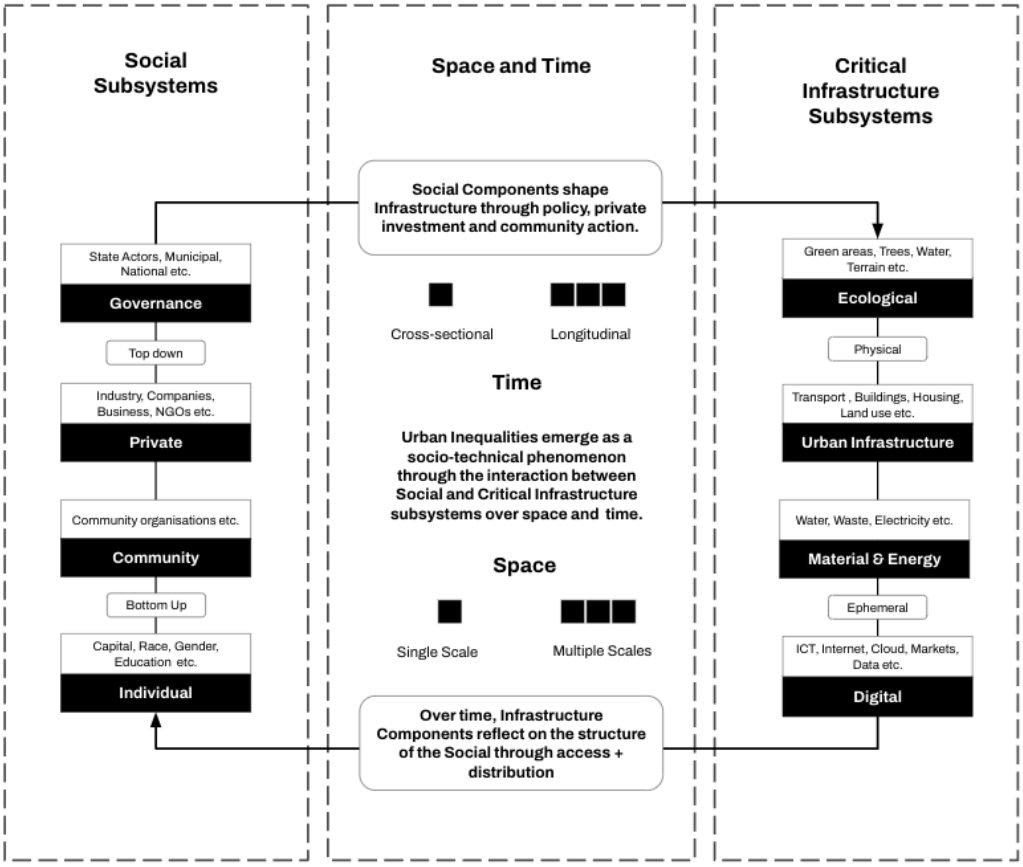

Figure 6.28: A conceptual framework of the urban as a complex socio-technical system developed in Chapter 2 of this dissertation. It frames urban inequalities as an emergent socio-technical phenomenon that develops over space and time.

R3: How can processes of neighbourhood development be connected to changes in policy to shine light on the structural drivers of inequalities in the distribution of housing?

Chapter 3 focuses on housing as critical infrastructure, connecting both the distribution and policy and stakeholder perspectives to answer the third research question. Housing inequalities are structural, reflecting persistent disparities in housing distribution across population groups (James et al., 2022). Structural housing inequalities are related to broader wealth disparities. According to the World Inequality Report (2021:3), the bottom 50% of the global population owns just 2% of total wealth, while the top 10% controls 76%. In the 21st century, rising private wealth and widening wealth-to-income ratios have been largely driven by increasing capital gains in housing (Fuller et al., 2020). This trend is deepening economic divides, creating a stark contrast between those unable to afford home ownership, single-home buyers, and multiple-property owners (Adkins et al., 2020; Mezaroş and Paccoud, 2022).

Housing inequalities are often analysed as outcomes of macroeconomic structural changes (Aalbers et al., 2017) or as local spatial-temporal processes shaping neighbourhood change. However, few studies systematically connect these perspectives. To bridge this gap, I critically examine the relationship between housing regulation and neighbourhood development. The third research question was addressed by developing a methodological framework for comparative trend analysis, linking multi-level housing policies with local neighbourhood development patterns. This methodology was applied to a case study of Rotterdam, Netherlands, using nearly 20 years of multi-dimensional neighbourhood data.

The analysis firstly reveals that increasing spatial polarisation between neighbourhoods has been driven by rising house and rent prices, alongside the depletion of social housing stock. Effectively, the barriers to moving between different kinds of neighbourhoods have increased over time. Secondly, it also shows that despite large, structural shifts in policy, the relative hierarchies of neighbourhood development patterns have persisted. This emphasises the role of path dependency, which implies that a sequence of events or decisions matters. Once a particular path is set in motion (i.e a neighbourhood is wealthy native Dutch to begin with or conversely socio-economically disadvantaged), it becomes increasingly difficult to deviate from it. These results suggest that neighbourhood path dependency is important in reproducing housing inequalities, highlighting that it is not only an outcome of macroeconomic processes, but also local socio-spatial conditions.

R4: How can theories of justice be operationalised to evaluate current neighbourhood accessibility?

Chapter 4 examines transport as critical infrastructure, linking both distribution and accessibility perspectives to address the fourth research question. Understanding how transport influences access is crucial to untangling its role in reproducing inequalities. Inequalities in accessibility are inevitable due to the constraints of urban growth, investment patterns, and the diverse needs of city populations (Golub and Martens, 2014). Nevertheless, tackling these disparities is essential for advancing the UN Sustainable Development Goals (particularly Goals 10 and 11), which emphasise sustainable, inclusive and equitable development. These concerns can be directly linked to broader debates on spatial justice, which are concerned with the fairness of how the spatial organisation of cities and the processes which shape them impact different people and places (Rocco et al., 2022; Soja, 2010).

To better understand the impacts of accessibility on spatial justice, I draw on moral and political philosophy to operationalise three well-established theories of justice: Egalitarianism, Utilitarianism, and Rawls' Egalitarianism. Together, I refer to this as the Mapping Accessibility for Ethically Informed Urban Planning Framework (MAP). An understanding of each theory led to the following reasoning: an Egalitarian approach prioritises equal access across regions, a Utilitarian approach

seeks to maximise access for regions with the greatest populations (even at the expense of a minority) and a Rawlsian approach provides the greatest access to those regions which are most vulnerable. To operationalise each ethical theory, I develop metrics that measure the gap between a neighbourhood's existing access and ideal level of access, based on that theory. This enables us to assess whether a neighbourhood meets the criteria for justice from each ethical perspective by visualising and comparing the outcomes through maps.

I applied MAP to evaluate access to places of employment in Monterrey (Mexico), Cape Town (South Africa) and Rotterdam (Netherlands). Through this evaluation, it is found that several factors shape spatial justice in cities:

- Each metric yields markedly diverse and distinct outcomes. This highlights how acknowledging the underlying ethical framework is an essential normative decision in any analysis of spatial justice.
- Achieving spatial justice rests on travel time. When travelling for 15 minutes, a neighbourhood might meet the requirements for justice, whereas when commuting for 60 minutes, it may not. Thus, spatial justice is not static but changes dynamically with temporal scale.
- Spatial morphology is an important contextual factor to consider within an analysis of spatial justice.
- In some cases, wealthier neighbourhoods did not meet the requirements for justice. This highlights the issue of "forced" versus "chosen" exclusion. Many wealthier residents would be in a position to own private vehicles to overcome accessibility barriers, which was not considered in the analysis.

The study illustrates that MAP facilitates comparative analysis, revealing universal or context-specific factors contributing to spatial justice. I also produced a software package to support the reproducibility of this framework, which can be found here[19] and is documented in Section 3.4 of the SM.

R5: How can we plan for a more just transportation future under conditions of uncertainty?

Chapter 5 examines scenario planning as an approach to urban policy-making for transportation planning, linking policy, accessibility and distribution perspectives to address the fifth research question. Transport and urban development occur within a complex institutional context and can therefore be considered a wicked problem - not solely technical, but also deeply political (Machiels et al., 2023; Rittel and Webber, 1973). Development is shaped by multiple, often unpredictable forces, including private investment, policy decisions, and climate change, leading to significant uncertainty. This complexity presents a challenge for planning a more just future, as traditional predictive data and modelling techniques struggle to fully account for such uncertainty.

In contrast to these approaches, contemporary scenario planning embraces uncertainty by accepting that the future is not static and/or predictable but is shaped by a set of driving forces interacting in complex ways. I received a grant to lead stakeholder engagement with multiple stakeholders across government, the private sector, and academia. I also collaborated with a local NGO, Young Urbanists, to organise a co-creation workshop in Cape Town. Through listening to the visions and concerns of the stakeholders and citizens, different pathways towards mobility justice in the future were realised. I developed quantitative urban network models to assess equity of access under each scenario using the MAP framework developed in Chapter 4. The insights showed that scenarios focused on integrated transport and active cycling would decrease inequities in the City. The major contribution of the work

[19] https://github.com/RuthJNelson/MAP-Mapping-Accessibility-for-Ethically-Informed-Urban-Planning

is that it highlights that transportation accessibility is not only an engineering problem but a human issue related to institutional capacity, trust, coordination, community agency and political vision.

6.2 Implications for Science

In this section, I reflect on this work's theoretical and empirical contributions to science, alongside my own reading of existing literature. Inequality is often measured in relation to income, with Thomas Piketty (2014) famously demonstrating that income inequality has risen sharply around the globe. While income inequality remains a pressing issue, I, along with others, argue that this approach is conceptually and methodologically limited in identifying the structural drivers of inequalities (Yap et al., 2021; Wolff and De Shalit, 2023).

Given these limitations, urban theorists have turned to alternative explanations, with many critiquing neo-liberal policies and practices as fundamental drivers of urban inequalities (Brenner and Theodore, 2005; Peck et al., 2009; Sassen, 2014). This has provided significant insights into how global neo-liberal processes and mechanisms shape unequal cities in different parts of the world and play a key role in the accumulation and spatialisation of capital. However, as others have pointed out, this perspective risks overlooking the localised drivers of inequality, such as urban governance structures, cultural dynamics and the historical effects of local policy (Parnell and Robinson, 2012). Furthermore, focusing on global neo-liberal perspectives may unintentionally downplay the role and agency of states and citizens in resisting, mitigating or reinforcing the structures which perpetuate urban inequalities.

In response to these gaps, Chapter 2 develops a theoretical framework that conceptualises urban inequalities as a complex socio-technical phenomenon. Rather than focusing solely on global neo-liberal practices or localised conditions, I adopt a relational approach as a distinctive mode of theorising. This begins by recognising that inequality is inherently multi-dimensional (Tonkiss, 2020). This framework integrates geospatial analysis with complexity science, building on the work of scholars who emphasise the value of linking geographical methods with complex systems thinking (Batty, 2013; Anderson and Dragićević, 2020). This approach examines the dynamic interactions between social subsystems (e.g., government, communities, the private sector, public policy) and technical subsystems (e.g., housing, transport, land use) at various scales, highlighting the interconnected nature of urban inequalities. As a starting point for researchers investigating inequalities, it shifts the focus from the *static* and *causal* to the *relational* and *dynamic*, informing how urban inequalities are represented, modelled, and measured. Time and scale become critical considerations, raising important questions about the spatial (street, neighbourhood, city) and temporal (tactical, long-term, or phased) dimensions of interventions and policies aimed at addressing urban inequalities. Additionally, viewing urban inequalities through the lens of socio-technical change enables a more dynamic analysis - moving beyond present conditions to consider both historical influences and future trajectories (Geels, 2019), as demonstrated in Chapters 3 and 5.

Understanding urban inequalities through a socio-technical lens not only reveals the interconnected nature of social and technical subsystems but also raises deeper normative questions about justice and equity. How inequalities manifest and persist, begs the question, who gets access to *what*, and *why*? Justice and equity are highly contested notions and create a normative space for exploring, debating, and applying ethical theories (Peyton Young; Lewis et al., 2021). Since 2010, there has been increasing debate in the transportation accessibility literature on which notions of justice apply to distributive spatial justice questions (Pereira et al., 2017; Martens, 2017; Van Wee and Mouter, 2021). Whilst I value and respect these intellectual debates, this work is positioned differently. Rather than assuming that any single theory of justice can serve as a universal principle for how opportunities and transport should be distributed, I argue that justice is inherently contextual. As Michael Walzer (1994) contends, the recognition that something is morally wrong, unfair, or unjust is often widely

shared. However, disagreements arise when defining what constitutes fairness or justice (Wolff and De Shalit, 2023). If universal notions of justice were truly uncontested, procedural justice, emphasising participatory processes in city planning, would not be necessary as everyone would share the same views, ideals and norms (Meerow et al., 2019).

With this background in mind, MAP represents a first step toward operationalising multiple metrics based on different ethical theories, allowing them to be collectively visualised and compared in maps. This approach differs fundamentally from previous work, which typically relies on a single metric based on one notion of justice, making direct comparisons impossible. Importantly, choosing a single theory is itself a normative decision which researchers often fail to acknowledge. Furthermore, as Lewis et al. (2021) points out, explicit equity considerations are rarely incorporated into transportation appraisals. Instead, cost-benefit analysis (CBA) remains the dominant practice, despite being underpinned by utilitarian principles that most practitioners are unaware of (Lucas et al., 2016). If procedural justice is taken seriously - especially in recognising unequal power relations and the right to the city (Harvey, 2003) - it becomes clear that values differ across contexts and communities. Thus, MAP aims to operationalise alternative notions of justice, making visible different issues and trade-offs that citizens and stakeholders can deliberate on. MAP provides a clear methodological contribution to urban and transport accessibility literature centred on equity and justice.

While MAP offers a way to operationalise multiple justice perspectives, it also highlights the tension between normative decision-making and the increasing reliance on data-driven methods. The rise of computational techniques and large-scale data analysis has transformed the social sciences, fueling debates about whether scientific fact can be established independently of theory (Kitchin, 2014). The *Fourth Paradigm*, as proposed by Hey et al. (2009), is Data-Driven Science, which suggests that data can drive the discovery of new knowledge. While data science techniques provide valuable insights into urban inequalities, I assert that any meaningful study in this domain must be anchored within clear scientific frameworks that are clearly positioned, both theoretically and contextually. This aligns with scholars who argue that researchers' world views and values fundamentally shape how they design, analyse, and interpret data (Kitchin, 2014; D'Ignazio and Klein, 2020; Franklin et al., 2022).

This need for theoretical clarity was central to the research presented in this dissertation. Each chapter established explicit frameworks that informed the research's design, analysis, and implementation. For instance, in Chapter 3, I engaged with existing literature to identify two dominant ontological positions in the study of housing inequalities. The first conceptualises housing inequalities as a consequence of macroeconomic forces such as global capital flows, neo-liberal policies, and state deregulation. The second situates housing inequalities within everyday neighbourhood-level practices and relations, emphasising the role of local socio-spatial conditions rather than overarching structures. Recognising that these perspectives are often treated in isolation, I developed an interdisciplinary methodological framework to bridge them, which can be applied to understand housing inequalities in other contexts, but also when studying the evolution of alternative public infrastructures in relation to policy development.

In an era where algorithms and data analytics increasingly influence urban decision-making, clarifying the underlying scientific frameworks is essential to ensuring that data-driven insights are theoretically and contextually grounded, and as a consequence are interpretable (O'Neil, 2016). However, theoretical clarity in data analysis alone is not sufficient; applying spatial data science effectively to urban inequalities requires engaging with the practical realities faced by urban practitioners and policymakers. As demonstrated in Chapter 5, incorporating citizen and stakeholder perspectives redefined understandings of accessibility in Cape Town and revealed the complexities that drive uncertainty in urban and transport development. This practical engagement allowed the co-creation of scenarios which provided insights into how the city might transition toward a more just urban condition by engaging with the impacts of each scenario on different neighbourhoods and populations. Typi-

cal predictive data science techniques would not be sufficient to predict future conditions for such a complex system under high levels of uncertainty. Thus, this work reinforces the necessity of interdisciplinary and transdisciplinary approaches, bridging theoretical frameworks with real-world applications to understand and address urban inequalities.

6.3 Implications for Society

In this section, I provide actionable insights for city officials, governments, and grassroots organisations based on the research insights derived from the work presented in this dissertation. I specify three pathways that drive urban inequalities and six key principles that define a *just city*.

The first pathway driving urban inequality in cities is the **unequal distribution of housing**. In Chapter 3, I document the increasing polarisation between the residents of neighbourhoods in South Rotterdam (non-native Dutch, low-income renters) and the affluent neighbourhoods in the far North (native Dutch, high-income homeowners). This shift occurred alongside structural changes in national housing policy, which introduced increased privatisation and deregulation of the housing sector. While the original intent of these policies was to lower barriers to home ownership (Forrest, 2021; Arundel and Ronald, 2019), their effects have not been equally distributed: the historically wealthiest neighbourhoods have had the greatest capital gains relative to their original house values.

In Chapter 4, the analysis of Cape Town and Monterrey showed that the most populous neighbourhoods are located on urban peripheries. The residents of these neighbourhoods are thus at a structural disadvantage when accessing everyday opportunities related to employment, health, recreation and education. The fact that these residents live in these conditions, does not necessarily represent a choice, but rather a constraint of a lack of affordable housing in more centrally located areas (Cooke et al., 2019; Carpio et al., 2021). This research provides evidence that discrepancies in housing prices across neighbourhoods can drive segregation, highlighting the need for governments to actively engage in the housing sector, rather than leaving it, as the old adage goes, "for the market to sort out".

The second pathway driving inequalities in cities is **unequal access to amenities**. Physical access to opportunities is achieved in two primary ways: either by walking proximity from one's place of residence or through being connected to them by transport. When amenities are not within walking proximity, affordable, safe, and efficient public transport becomes crucial to access them, especially for lower-income residents who do not own cars. In Chapter 4, I operationalised three theories of justice to assess the distribution of access to places of employment. This analysis revealed how a neighbourhood may be disadvantaged when accessing places of employment according to a number of factors related to unequal access, insufficient access for its population size or level of socio-economic deprivation.

Chapter 5 further illustrates these issues, showing how residents in Cape Town who rely on public transport face numerous barriers to accessing opportunities. These barriers stem not only from a lack of infrastructure but also from social, institutional, and governance factors, including unreliable transport, long travel times, communication barriers, safety concerns, low community agency, institutional fragmentation, and the high cost of transport for the commuter. These challenges extend beyond individual choices, highlighting how a city's spatial organisation and institutional structures can perpetuate structural barriers, reinforcing urban inequalities. This emphasises the need for communities to actively engage in issues and decisions related to transportation and urban development. Further, different actors across government and the private sector must mobilise collectively towards shared transport and urban visions that include equity and justice considerations.

The third pathway driving inequalities in cities is **fragmented governance and weak community agency**. In Chapter 5, the analysis of Cape Town's transport landscape revealed the fragmentation

of transport modes operated by various companies and governed by different levels of authority. Local government representatives highlighted how this fragmentation creates a significant barrier to aligning development goals, limiting their capacity to design, implement, and plan cohesive transport systems. As a result, citizens represented by democratically elected government officials have less agency to influence transport-related decisions.

In Cape Town, certain transport modes are owned by different private companies, whose primary goal is profitability, meaning that they are less likely to invest in infrastructure in socio-economically disadvantaged areas. This fragmentation of infrastructure ownership is not unique to Cape Town or the transport sector. In Chapter 3, I document similar trends in the Netherlands, where the unbundling and privatisation of housing have led to similar governance challenges. These findings resonate with studies from around the world, showing how fragmented governance in sectors like energy (Morrison, 2022), transport (Mccartney and Stittle, 2013), water (Cornell Chronicle[20], 2022), and housing (Madden and Marcuse, 2016) weakens the decision-making power of governments. A lack of coordination, trust, and shared goals between stakeholders exacerbates governance challenges and weakens the democratic agency of citizens.

The three pathways driving urban inequalities are not mutually exclusive and the deepening disparities that characterise many cities stem from the combination of these factors (Nijman and Wei, 2020). Addressing urban inequalities is thus particularly challenging, as they are complex and multifaceted. These issues are inherently multi-scalar, shaped by the decisions of various stakeholders at local, regional, national, and global levels. While global capital flows and national policies often influence urban development in ways beyond municipal control (Sassen, 2014), local governments still possess significant agency (Pieterse, 2019; Tonkiss, 2020). In particular, local governments play a crucial role in minimising pathways of inequality at the neighbourhood scale. With this in mind, I propose six principles characterising a just city. These principles are not meant to serve as a definitive blueprint, but as a starting point for further research and contextualisation. Achieving these principles would require a socio-technical transition involving policy, regulatory, institutional, behavioural and infrastructural changes, all of which are subject to further exploration. They reflect my understanding, as shaped by the findings of this research.

1. A just city has social and affordable housing in every neighbourhood

A just city has social and affordable housing (both to rent and/or buy) in all neighbourhoods. A just city maximises choice for low- and middle-income earners and their ability to live in neighbourhoods with public services and amenities. There are a number of regulatory measures which could be explored, such as land value taxation (Kerr, 2016) rent restrictions, housing subsidies, rent stabilisation, eviction protections, inclusionary zoning and incentives for affordable housing development (Lubell, 2016). This principle directly responds to Pathway 1, which drives urban inequalities through the unequal distribution of housing.

A relevant example of a contextually driven pilot project which seeks to address housing inequalities is the Empower Shack Project[21] in the township of Khayelitsha in Cape Town. Khayelitsha, built under the apartheid government, is a historically disadvantaged area that has expanded rapidly through informal settlements where residents often live in substandard conditions with limited access to basic services. Empower Shack responds to the direct needs of Khayelitsha's residents by offering a new model for housing that combines affordability, incremental construction, and community participation with the aim of incrementally improving shacks to legal housing, as seen in Figure 6.29. This model presents an alternative to traditional housing projects, which are often costly, slow to

[20] https://news.cornell.edu/stories/2022/04/privatization-poverty-threaten-water-affordability
[21] https://architizer.com/projects/empower-shack/

implement, and disconnected from the needs of residents. By proving the effectiveness of community-driven, incremental housing solutions, it provides evidence for policymakers that addressing housing inequality in South Africa requires more flexible, context-specific approaches.

Figure 6.29: This is a picture of the Empower Shack project when it was first completed. It is built partially with brick and timber clad in corrugated iron. Reference: https://groundup.org.za/article/73-families-move-into-newly-built-alternative-affordable-housing-models-in-khayelitsha/

2. A just city has mixed land use in every neighbourhood

A just city's neighbourhoods are characterised by mixed land use. Consequently, a just city's citizens can access essential amenities (e.g. medical, educational, recreational, retail etc.) at minimum travel time and little to no cost. This reduces carbon emissions and consequently has environmental benefits through reduced travel. There are a number of measures which could be explored, such as zoning for mixed-use (Mandelker, 2023), government investment in specific neighbourhoods (Harvey, 2008) and tax incentives to attract investors to specific neighbourhoods (Fainstein, 2011). This principle directly responds to Pathway 2, which drives inequalities through the unequal distribution of access to amenities.

A pertinent example of this principle in action is the Bo01 project[22] in Malmö, Sweden, where the city revitalised its Western Harbour area after the decline of its shipbuilding industry. The project, launched in 2001, transformed the area into a sustainable, mixed-use neighbourhood. It became a model for sustainable, mixed-use neighbourhoods, demonstrating how such developments can improve access to amenities. Key features include:

[22]https://www.21stcenturydevelopment.org/media/1045/bo01pdf.pdf

- Mixed Land Use: Residential, commercial, and recreational spaces were integrated, enhancing community life and accessibility.
- Sustainability: The development used renewable energy sources and energy-efficient buildings, reducing living costs and environmental impact.
- Community Engagement: Local residents were involved in planning, fostering a sense of ownership and social responsibility.

3. A just city is walkable and cyclable

A just city provides infrastructure for walking and cycling, ensuring that its citizens (regardless of race, ethnicity, gender, age or sexuality) can walk and cycle safely at any time. A just city prioritises these modes to support social inclusion, ecological justice and the overall health of a population by encouraging active travel. There are a number of measures which could be explored, such as the widening of pavements, provision of cycling infrastructure, carbon tax on motor vehicles, removal of parking bays, policing of streets and public lighting (World Bank Group[23], 2018). This principle directly responds to Pathway 2, which drives inequalities through the unequal distribution of access to amenities.

A good example of this principle in action is Mexico City's initiative, "Muévete en Bici"[24] (Move by Bike). Over 50 kilometres of roads are closed to vehicles every Sunday, creating safe spaces for cyclists, pedestrians, and skaters, as seen in Figure 6.30. The program encourages active transportation, improves air quality, and fosters a cycling culture. Mexico City's initiative highlights the potential for temporary measures to promote long-term changes in urban transport, supporting sustainable mobility and healthier communities. The key outcomes include:

- Cycling Adoption: A safe environment motivates more residents to cycle regularly.
- Public Health: Increased cycling improves health and reduces pollution.
- Community Engagement: The event fosters social interaction and inclusivity.
- Policy Inspiration: Other cities can replicate this model for sustainable mobility.

4. A just city provides coordinated, reliable, affordable, efficient and safe public transport

A just city has many different forms of transport which cater to different citizens' needs. A just city provides coordinated, reliable, affordable, efficient and safe public transport at all times of the day, regardless of where a citizen lives. A just city does not profit off the movements of the poor or silo them to a specific part of the city. There are a number of measures which can be explored, such as integrated ticketing and fares (Alhassan et al., 2023), subsidised ticketing for poorer residents (Guzman and Hessel, 2022), accessibility- based planning and regulation which ensures different operators coordinate timetables (Liu et al., 2021). This principle directly responds to Pathway 2, which drives inequalities through the unequal distribution of access to amenities.

A notable example is the TransMiCable cable car system in Bogotá. The cable car system serves low-income communities by improving accessibility and reducing travel time. Many residents of Ciudad Bolívar, a marginalised, hilly neighbourhood with over 700,000 people, previously endured 1.5-2 hour commutes to central Bogotá. With TransMiCable, this has been reduced to just 13 minutes. Integrated with the TransMilenio bus system, it provides an affordable, reliable, and efficient alternative

[23] https://documents1.worldbank.org/curated/en/157521557142749465/pdf/Practical-Guidance-and-Good-Practice-Examples.pdf
[24] https://www.wheresidewalksend.com/biking-mexico-city/

Figure 6.30: This figure is a picture of Mexico City's "Move by Bike Initiative", which transforms roads into cycling-only streets every Sunday. Reference: Taken by the Author

to costly taxis and slow buses. Beyond transport, the cable car stations serve as community hubs with libraries, cultural spaces, and local businesses, fostering social and economic growth. Additionally, as a sustainable, electric-powered solution, it reduces carbon emissions and air pollution, improving public health. The success of Bogotá's cable cars has made them a model for other Latin American cities, such as Mexico City as seen in Figure 6.31.

Figure 6.31: This figure shows a cable car system on the outskirts of Mexico City, inspired by the Bogota TransMiCable cable car system, which provides residents living in a favela with efficient, cheap and accessible public transport. Reference: Taken by the Author

5. A just city has coordinated and localised planning

A just city has coordinated development of transport and housing. Housing is not developed without transport connections to link a community to everyday services. A just city's private and public stakeholders, inclusive of citizens, work together towards a shared vision to develop socially inclusive neighbourhoods through localised planning. There are a number of measures which can be explored, such as transit-orientated planning (Liu et al., 2020), state investment to support projects that maximise access to transit and promote the joint development of housing (Achieving Housing Abundance and Freemark, 2023) and inclusion of transit access metrics to evaluate the transit accessibility of affordable housing sites (Smith et al., 2021). This principle directly responds to Pathway 3, which drives inequalities through fragmented planning and weak governance.

A prime example of a city which has embraced coordinated development is Copenhagen in Denmark. Since 1947, the city has strategically developed urban growth along five "fingers" extending from the

city centre, each following a rail corridor. Housing, offices, and retail are clustered along train and metro stations, ensuring that residents have access to essential services. Additionally, Copenhagen has prioritised bicycle infrastructure in its planning, reducing reliance on cars and promoting sustainable mobility.

6. A just city is shaped through community participation and representation

A just city has strong community representation and agency. A just city protects communities' right to influence their cities' development and does not allow market conditions to forcefully displace people from their local communities through gentrification or discriminatory policies. A just city has policies which allow citizens to develop the activities and relationships that give shape to life within the city, the neighbourhood and for the individual. There are a number of measures which can be explored, such as participatory budgeting (Cabannes, 2015), citizen assemblies (Lage et al., 2023) and digital tools (Batty et al., 2012). This principle directly responds to Pathway 3, which drives inequalities through fragmented planning and weak governance.

An example of this principle in action is the "Superblocks"[25] initiative in Barcelona, Spain. Through public workshops and neighbourhood assemblies, residents co-designed the layout of the Superblocks, ensuring that local voices were central to the decision-making process. The city also embraced local activism and pilot projects, allowing small trials before expanding the project city-wide. Additionally, online consultation portals provided residents with a digital platform to propose and vote on urban improvements, further enhancing community agency. As a result, Barcelona's approach has led to increased green spaces, reduced pollution, and stronger neighbourhood cohesion, demonstrating the power of community-driven design in fostering a just city.

6.4 Future research and limitations

In this section, I expand on areas for future research and reflect on the limitations of this work, ranging from general to specific.

General recommendations and limitations of this research

The most pressing area for future research should be focusing on the policy instruments, regulations, and processes that support socio-technical transitions towards a just city. A particular area of concern would be the funding mechanisms, regulatory frameworks, and institutional capacities that cities could adopt to achieve the just city principles. One example would be focusing on the policy instruments required to achieve equitable distribution of affordable housing, related to land use zoning, tax incentives, rent control and state investment. Another example would be focusing on what institutional capacities are needed to support the principle of community representation. Could this be achieved through citizen assemblies or a digital solution that allows citizens to vote on key infrastructure developments? Another important consideration that underpins this work is expanding an understanding of the preferences of stakeholders, policymakers and citizens in defining justice within different contexts. This is a fundamental research gap that has been given scant attention.

Data quality is essential for methodological advancements in spatial data science for urban inequalities. Future research should focus on the systematic development of longitudinal data sets and standards, particularly in countries where data is not readily available. For example, this presented a limitation in Chapter 4 in the analysis of Monterrey and Cape Town, where there was no publicly available data on informal transport in these cities when the study was conducted. The availability of data sets is imperative to ensure further research in these contexts. Furthermore, developing standards

[25] https://www.c40.org/case-studies/barcelona-superblocks

for how data is collected and represented is important to increase interoperability and reduce bias, misrepresentation and missing data, which can potentially reinforce existing inequalities. Scientific research in this area can guide local governments on ways to build datasets, processes, analyses, and visualisation for their cities, which aid them in addressing inequalities of access, distribution and policy.

Each empirical case relies on data at the neighbourhood scale. As a result, these studies are constrained by the aggregation of socio-economic data within administrative neighbourhood boundaries, which may obscure individual experiences related to factors such as age, gender, or perceptions of safety. Moreover, the scale and delineation of neighbourhood boundaries influence the results, a well-documented issue in geographical research known as the Modifiable Areal Unit Problem (MAUP). Nonetheless, as I argue throughout this work, administrative neighbourhood boundaries play a crucial role in urban resource management. They reflect governance differences between local councils and define the municipality a neighbourhood belongs to, shaping policies, zoning laws, investment opportunities, and governance approaches.

Specific recommendations and limitations of this research

The research in Chapter 2 could be expanded to include alternative keyword searches, 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. It could also be refined by focusing on specific dimensions of inequalities and targeting certain contexts. Furthermore, I 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 include many more articles.

Future analysis resulting from Chapter 3 should focus on the implications of both the *size* and *scale* at which policy interventions are implemented in relation to their effects on housing inequalities. Furthermore further exploration into the development of methods to relate the analysis of past, current and future policy with spatial-temporal analysis has the potential to enhance understanding of both the "bottom-up" effects and "top-down" structures which reproduce complex urban problems, such as housing inequalities. The existing empirical work could be expanded to include other cities in the Netherlands to investigate further the dynamics between housing policy and the socio-spatial trajectories of neighbourhoods in other cities. It could also utilise longitudinal data, at a lower level than the neighbourhood unit.

The research in Chapter 4 could be expanded by focusing on the expansion of MAP to include other theories of justice, such as sufficientarianism and prioritarianism. A second area of interest is to apply MAP to evaluate amenities beyond places of employment, such as healthcare and educational opportunities, and alternative times of the day, if such transport data is available. It is important to recognise that the empirical research was limited by a lack of data on para-transit, bus, private car ownership, cycling networks and informal land use. If such data is available this study could be enriched.

The research in Chapter 5 could be expanded through the development of qualitative metrics for equity. The methods applied to the scenario evaluations could be enriched with qualitative assessments of equity and justice by stakeholders and citizens.

6.5 Conclusion

This research builds on critical urban theory related to inequalities. It bridges theory with practice by formulating frameworks, metrics, and tools and engaging with stakeholders to understand, measure and realise pathways towards addressing urban inequalities. It deepened an understanding of how urban inequalities are reproduced in everyday life through 3 major pathways and established 6 principles of the Just City and areas for future research. To conclude, I believe that the city belongs to all of us, and it should be a place that provides opportunities for all. If we work together, we can create a more just and equitable future for all.

References

Aalbers, M. B., Hochstenbach, C., Bosma, J., and Fernandez, R. (2020). The Death and Life of Private Landlordism: How Financialized Homeownership Gave Birth to the Buy-To-Let Market. *Housing, Theory and Society*, 38:541 – 563.

Aalbers, M. B., Loon, J. V., and Fernandez, R. (2017). The Financialization of A Social Housing Provider. *International Journal of Urban and Regional Research*, 41(4):572–587. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2427.12520.

Achieving Housing Abundance and Freemark, Y. (2023). Achieving Housing Abundance Near Transit.

Adkins, L., Cooper, M., and Konings, M. (2020). *The Asset Economy*. Polity.

Aguilera, A. (2016). Failed Markets: The Crisis in the Private Production of Social Housing in Mexico. *Latin American Perspectives*, 44(2):38–49.

Alda-Vidal, C., Kooy, M., and Rusca, M. (2018). Mapping operation and maintenance: an everyday urbanism analysis of inequalities within piped water supply in Lilongwe, Malawi. *Urban Geography*, 39(1):104–121.

Alhassan, I. B., Matthews, B., Toner, J. P., and Susilo, Y. O. (2023). Examining the effect of integrated ticketing on mode choice for interregional commuting: Studies among car commuters. *International Journal of Sustainable Transportation*, 17(3):245–257. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/15568318.2022.2029634.

Amer, M., Daim, T. U., and Jetter, A. (2013). A review of scenario planning. *Futures*, 46:23–40.

Anaya-Boig, E., Cebollada, , and Castelló Bueno, M. (2022). Measuring spatial inequalities in the access to station-based bike-sharing in Barcelona using an Adapted Affordability Index. *Journal of Transport Geography*, 98.

Anderson, T. and Dragićević, S. (2020). Complex spatial networks: Theory and geospatial applications. *Geography Compass*, 14(9):e12502. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gec3.12502.

Anselin, L. (2002). Under the hood: Issues in the specification and interpretation of spatial regression models. *Agricultural Economics*, 27(3):247–267.

Arribas-Bel, D. (2019). A course on Geographic Data Science. *Journal of Open Source Education*, 2(14):42.

Arundel, R. and Ronald, R. (2020). The false promise of homeownership: Homeowner societies in an era of declining access and rising inequality. *Urban Studies*, 58:1120 – 1140.

Arundel, R. and Ronald, R. (2021). The false promise of homeownership: Homeowner societies in an era of declining access and rising inequality. *Urban Studies*, 58(6):1120–1140. Publisher: SAGE Publications Ltd.

Avin, U. (2016). Sketch Tools for Regional Sustainability Scenario Planning. Technical report.

Avin, U. and Goodspeed, R. (2020). Using Exploratory Scenarios in Planning Practice: A Spectrum of Approaches. *Journal of the American Planning Association*, 86(4):403–416. Publisher: Routledge _eprint: https://doi.org/10.1080/01944363.2020.1746688.

Azmoodeh, M., Haghighi, F., and Motieyan, H. (2023). The capability approach and social equity in transport: Understanding factors affecting capabilities of urban residents, using structural equation modeling. *Transport Policy*, 142:137–151.

Bagchi-Sen, S., Franklin, R. S., Rogerson, P., and Seymour, E. (2020). Urban inequality and the demographic transformation of shrinking cities: The role of the foreign born. *Applied Geography*, 116:102168.

Basiri, A. and Brunsdon, C. (2022). Missing data as data. *Patterns*, 3(9):100587.

Batty, M. (2009). Accessibility: In Search of a Unified Theory. *Environment and Planning B: Planning and Design*, 36(2):191–194. Publisher: SAGE Publications Ltd STM.

Batty, M. (2013). *The New Science of Cities*. MIT Press, Cambridge, MA, USA.

Batty, M., Axhausen, K. W., Giannotti, F., Pozdnoukhov, A., Bazzani, A., Wachowicz, M., Ouzounis, G., and Portugali, Y. (2012). Smart cities of the future. *The European Physical Journal Special Topics*, 214(1):481–518.

Bavel, B. v. and Frankema, E. (2017). Wealth Inequality in the Netherlands, c. 1950-2015: The paradox of a Northern European welfare state. *Tijdschrift voor Sociale en Economische Geschiedenis = The Low Countries Journal of Social and Economic History*, 14(2):29–62. Publisher: Amsterdam University Press.

Beekers, W. (2012). *Het bewoonbare land: Geschiedenis van de volkshuisvestingsbeweging in Nederland*. PhD-Thesis – Research external, graduation internal, BOOM. ISBN: 9789461056573.

Bentham, J. (1907). *An Introduction to the Principles of Morals and Legislation*. Clarendon Press, Oxford, 2 edition.

Bergman, P., Chetty, R., DeLuca, S., Hendren, N., Katz, L. F., and Palmer, C. (2024). Creating Moves to Opportunity: Experimental Evidence on Barriers to Neighborhood Choice. *American Economic Review*, 114(5):1281–1337.

Berry, S., Carr, P., Kool, B., Mohal, J., Morton, S., and Grant, C. (2017). Housing tenure as a focus for reducing inequalities in the home safety environment: evidence from Growing Up in New Zealand. *Australian and New Zealand Journal of Public Health*, 41(5):530–534.

Bettencourt, L. M. A. (2013). The Origins of Scaling in Cities. *Science*, 340(6139):1438–1441. Publisher: American Association for the Advancement of Science.

Bibri, S. E. (2019). On the sustainability of smart and smarter cities in the era of big data: an interdisciplinary and transdisciplinary literature review. *Journal of Big Data*, 6(1):25.

Blanco, J. and Apaolaza, R. (2018). Socio-territorial inequality and differential mobility. Three key issues in the Buenos Aires Metropolitan Region. *Journal of Transport Geography*, 67:76–84.

Blondeel, M., Price, J., Bradshaw, M., Pye, S., Dodds, P., Kuzemko, C., and Bridge, G. (2024). Global energy scenarios: A geopolitical reality check. *Global Environmental Change*, 84:102781.

Blume, L. (2015). *Agent-Based Models for Policy Analysis*. National Academies Press (US). Publication Title: Assessing the Use of Agent-Based Models for Tobacco Regulation.

Blumenberg, E. and King, H. (2021). Jobs–Housing Balance Re-Re-Visited. *Journal of the American Planning Association*, 87:1–13.

Boeing, G. (2020a). A multi-scale analysis of 27,000 urban street networks: Every US city, town, urbanized area, and Zillow neighborhood. *Environment and Planning B: Urban Analytics and City Science*, 47(4):590–608. Publisher: SAGE Publications Ltd STM.

Boeing, G. (2020b). Planarity and street network representation in urban form analysis. *Environment and Planning B: Urban Analytics and City Science*, 47(5):855–869. Publisher: SAGE Publications Ltd STM.

Boelhouwer, P. (2020). The housing market in The Netherlands as a driver for social inequalities: proposals for reform. *International Journal of Housing Policy*, 20(3):447–456.

Boelhouwer, P. and Priemus, H. (2014). Demise of the Dutch social housing tradition: impact of budget cuts and political changes. *Journal of Housing and the Built Environment*, 29(2):221–235. Publisher: Springer.

Bonnet, C., Garbinti, B., and Grobon, S. (2018). Rising inequalities in access to home ownership among young households in France, 1973-2013. *Economie et Statistique*, 2018(500-502):117–138.

Boschken, H. (2022). Income inequality and the imprint of globalization on U.S. metropolitan areas. *Cities*, 121.

Bourdieu, P. (2002). *Distinction: a social critique of the judgement of taste*. Harvard Univ. Press, Cambridge, Mass, 11. print edition.

Braun, V. and Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2):77–101. Publisher: Routledge _eprint: https://www.tandfonline.com/doi/pdf/10.1191/1478088706qp063oa.

Brenner, N. and Theodore, N. (2005). Neoliberalism and the urban condition. *City*, 9(1):101–107. Publisher: RSA Website _eprint: https://doi.org/10.1080/13604810500092106.

Bulkeley, H. and Castán Broto, V. (2012). Government by experiment? Global cities and the governing of climate change. *Transactions of the Institute of British Geographers*, (3):1–15.

Byrne, M. (2020). Generation rent and the financialization of housing: a comparative exploration of the growth of the private rental sector in Ireland, the UK and Spain. *Housing Studies*, 35(4):743–765. Publisher: Routledge _eprint: https://doi.org/10.1080/02673037.2019.1632813.

Cabannes, Y. (2015). The impact of participatory budgeting on basic services: municipal practices and evidence from the field. *Environment & Urbanization*, 27(1):257–284. Publisher: SAGE Publications Ltd.

Calenbuhr, V. (2020). Chapter 11 - Complexity Science in the Context of Policymaking. In Šucha, V. and Sienkiewicz, M., editors, *Science for Policy Handbook*, pages 118–127. Elsevier.

Campbell, S. D. and Zellner, M. (2020). Wicked Problems, Foolish Decisions: Promoting Sustainability through Urban Governance in a Complex World Symposium: Governing Wicked Problems. *Vanderbilt Law Review*, 73.

Carpio, A., Ponce-Lopez, R., and Lozano-García, D. F. (2021). Urban form, land use, and cover change and their impact on carbon emissions in the Monterrey Metropolitan area, Mexico. *Urban Climate*, 39:100947.

Cassiers, T. and Kesteloot, C. (2012). Socio-spatial Inequalities and Social Cohesion in European Cities. *Urban Studies*, 49(9):1909–1924.

Castells, M. (1996). *The Rise of The Network Society: v.1*. Malden, Mass.

Cervero, R. (1996). Jobs-Housing Balance Revisited: Trends and Impacts in the San Francisco Bay Area. *Journal of the American Planning Association*, 62(4):492–511. Publisher: Routledge _eprint: https://doi.org/10.1080/01944369608975714.

Chan, H.-Y., Xu, Y., Chen, A., and Zhou, J. (2023). Choice and equity: A critical analysis of multi-modal public transport services. *Transport Policy*, 140:114–127.

Chan, K. W. (2010). The Household Registration System and Migrant Labor in China: Notes on a Debate. *Population and Development Review*, 36(2):357–364. Publisher: [Population Council, Wiley].

Chancel, L., Piketty, T., Saez, E., and Zucman, G. (2022). World Inequality Report.

Chandler, D. (2023). *Free and Equal: What Would a Fair Society Look Like?* Allen Lane.

Chen, P. N. and Karimi, K. (2017). *The impact of a new transport system on the neighbourhoods surrounding the stations: The cases of Bermondsey and West Ham, London.*

Chen, W.-H., Myles, J., and Picot, G. (2012). Why Have Poorer Neighbourhoods Stagnated Economically while the Richer Have Flourished? Neighbourhood Income Inequality in Canadian Cities. *Urban Studies*, 49(4):877–896.

Chen, Y., Yue, W., and La Rosa, D. (2020). Which communities have better accessibility to green space? An investigation into environmental inequality using big data. *Landscape and Urban Planning*, 204:103919.

Cheshire, P. (2012). Are Mixed Community Policies Evidence Based? A Review of the Research on Neighbourhood Effects. In van Ham, M., Manley, D., Bailey, N., Simpson, L., and Maclennan, D., editors, *Neighbourhood Effects Research: New Perspectives*, pages 267–294. Springer Netherlands, Dordrecht.

Chetty, R. and Hendren, N. (2018). The Impacts of Neighborhoods on Intergenerational Mobility II: County-Level Estimates*. *The Quarterly Journal of Economics*, 133(3):1163–1228.

Chetty, R., Jackson, M. O., Kuchler, T., Stroebel, J., Hendren, N., Fluegge, R. B., Gong, S., Gonzalez, F., Grondin, A., Jacob, M., Johnston, D., Koenen, M., Laguna-Muggenburg, E., Mudekereza, F., Rutter, T., Thor, N., Townsend, W., Zhang, R., Bailey, M., Barberá, P., Bhole, M., and Wernerfelt, N. (2022). Social capital II: determinants of economic connectedness. *Nature*, 608(7921):122–134. Publisher: Nature Publishing Group.

Christophers, B. (2021). A tale of two inequalities: Housing-wealth inequality and tenure inequality. *Environment and Planning A: Economy and Space*, 53(3):573–594. Publisher: SAGE Publications Ltd.

CITP (2023). Comprhensive Integrated Transport Plan. Technical report, Urban Mobility City of Cape Town.

Clifton, K. and Moura, F. (2017). Conceptual Framework for Understanding Latent Demand: Accounting for Unrealized Activities and Travel. *Transportation Research Record: Journal of the Transportation Research Board*, 2668:78–83.

Cohen, T. (2020). Tools for addressing transport inequality: A novel variant of accessibility measurement. *Journal of Transport Geography*, 88.

Cooke, S., Durakovic, E., Onyango, G. M., Simon, D., Singh, K., Ranhagen, U., Lejdebro, M., and Davies, C. (2019). Applying a multi-level perspective to examine the potential transition to an accessibility-based approach to transport planning: Insights from cities in Sweden, Kenya and South Africa. Ottawa, Ontario.

Cooper, E. and Vanoutrive, T. (2022). Is accessibility inequality morally relevant?: An exploration using local residents' assessments in Modesto, California. *Journal of Transport Geography*, 99.

Coulter, R., Ham, M. v., and Findlay, A. M. (2016). Re-thinking residential mobility: Linking lives through time and space. *Progress in Human Geography*, 40(3):352–374. Publisher: SAGE Publications Ltd.

Crooks, A., Malleson, N., Manley, E., and Heppenstall, A. (2019). *Agent-Based Modelling and Geographical Information Systems: A Practical Primer*. SAGE Publications Ltd, Thousand Oaks, CA, first edition edition.

Crul, M. and Schneider, J. (2010). Comparative integration context theory: participation and belonging in new diverse European cities. *Ethnic and Racial Studies*, 33(7):1249–1268. Publisher: Routledge _eprint: https://doi.org/10.1080/01419871003624068.

Crul, M., Scholten, P., and van de Laar, P., editors (2019). *Coming to Terms with Superdiversity: The Case of Rotterdam*. IMISCOE Research Series. Springer International Publishing : Imprint: Springer, Cham, 1st ed. 2019 edition.

Daniels, R. and Mulley, C. (2013). Explaining walking distance to public transport: The dominance of public transport supply. *Journal of Transport and Land Use*, 6(2):5–20. Publisher: Journal of Transport and Land Use.

Davila, J. (2013). *Urban Mobility and Poverty: Lessons from Medellin and Soacha, Colombia*.

de Bruijn, H. and ten Heuvelhof, E. (2018). *Management in networks, second edition*. Routledge - Taylor & Francis Group.

de Roo, G., Yamu, C., and Zuidema, C. (2020). *Handbook on Planning and Complexity*.

Delamater, P. L. (2013). Spatial accessibility in suboptimally configured health care systems: a modified two-step floating catchment area (M2SFCA) metric. *Health & Place*, 24:30–43.

Delbosc, A. and Currie, G. (2011). The spatial context of transport disadvantage, social exclusion and well-being. *Journal of Transport Geography*, 19(6):1130–1137.

Delmelle, E. (2016). Mapping the DNA of Urban Neighborhoods: Clustering Longitudinal Sequences of Neighborhood Socioeconomic Change. *Annals of the American Association of Geographers*, 106:36–56.

Delmelle, E. C. (2021). GIScience and neighborhood change: Toward an understanding of processes of change. *Transactions in GIS*, n/a(n/a). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/tgis.12871.

Demitiry, M., Higgins, C. D., Páez, A., and Miller, E. J. (2022). Accessibility to primary care physicians: Comparing floating catchments with a utility-based approach. *Journal of Transport Geography*, 101:103356.

Dewilde, C. (2017). Explaining the declined affordability of housing for low-income private renters across Western Europe. *Urban Studies (Edinburgh, Scotland)*, 55:2618 – 2639.

Dieleman, F. M. and van Kempen, R. (1994). The Mismatch of Housing Costs and Income in Dutch Housing. *Netherlands Journal of Housing and the Built Environment*, 9(2):159–172. Publisher: Springer.

D'Ignazio, C. (2017). Creative data literacy: Bridging the gap between the data-haves and data-have nots. *Information Design Journal*, pages 6–18.

D'Ignazio, C. and Klein, L. (2020). *Data Feminism.* MIT Press.

Dong, C., Schoups, G., and van de Giesen, N. (2013). Scenario development for water resource planning and management: A review. *Technological Forecasting and Social Change*, 80(4):749–761.

Dong, H. (2018). The impact of income inequality on rental affordability: An empirical study in large American metropolitan areas. *Urban Studies*, 55(10):2106–2122. Publisher: SAGE Publications Ltd.

Dorling, D. (2010). All connected? Geographies of race, death, wealth, votes and births. *Geographical Journal*, 176(3):186–198.

Duba, S. (2023). WATCH: Despite two buses being torched, it's business as usual for Golden Arrow amid traffic chaos caused by taxi strike.

Easley, D. and Kleinberg, J. (2010). *Networks, Crowds, and Markets:*. Cambridge University Press, Cambridge.

Entzinger, H. and Engbersen, G. (2014). Rotterdam: A Long-Time Port of Call and Home to Immigrants. page 19.

Faber, J. (2021). Contemporary echoes of segregationist policy: Spatial marking and the persistence of inequality. *Urban Studies*, 58(5):1067–1086.

Fainstein, S. (2016). Spatial Justice and Planning. In Susan Fainstein and James DeFellipis, editors, *Readings in Planning Theory*, pages 260–274. Wiley, Oxford.

Fainstein, S. and DeFilipp, J. (2016). *Readings in Planning Theory.* Wiley, Oxford, 4th edition edition.

Fainstein, S. S. (2011). *The Just City.* Cornell University Press.

Fields, D. and Uffer, S. (2016). The financialisation of rental housing: A comparative analysis of New York City and Berlin. *Urban Studies*, 53(7):1486–1502. Publisher: SAGE Publications Ltd.

Fol, S. and Gallez, C. (2014). Social inequalities in urban access. Better ways of assessing transport improvements. In *Urban Access for the 21st Century: Finance and Governance Models for Transportation Infrastructure*, pages 46–86. Routledge, New York.

Forrest, R. (2021). Housing wealth, social structures and changing narratives. *International Journal of Urban Sciences*, 25(1):1–15.

Forrest, R. and Hirayama, Y. (2018). Late home ownership and social re-stratification. *Economy and Society*, 47:257 – 279.

Forum, W. E. (2017). Women own less than 20% of the world's land. It's time to give them equal property rights.

Franklin, R. (2023). Quantitative methods II: Big theory. *Progress in Human Geography*, 47(1):178–186. Publisher: SAGE Publications Ltd.

Franklin, R. S., Delmelle, E. C., Andris, C., Cheng, T., Dodge, S., Franklin, J., Heppenstall, A., Kwan, M.-P., Li, W., McLafferty, S., Miller, J. A., Munroe, D. K., Nelson, T., Öner, , Pumain, D., Stewart, K., Tong, D., and Wentz, E. A. (2022). Making Space in Geographical Analysis. *Geographical Analysis*, n/a(n/a). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gean.12325.

Freire, P. (1970). *Pedagogy of the oppressed.* Bloomsbury Publishing, New York.

Fuller, G., Johnston, A., and Regan, A. (2020). Housing prices and wealth inequality in Western Europe. *West European Politics*, 43(2):297–320.

Funtowicz, S. and Ravetz, J. (2020). Post-Normal Science: How Does It Resonate With the World of Today? In *Science for Policy Handbook*, pages 119–127. Elsevier, Amsterdam.

Gabadinho, A., Ritschard, G., Müller, N. S., and Studer, M. (2011). Analyzing and Visualizing State Sequences in *R* with **TraMineR**. *Journal of Statistical Software*, 40(4).

García-Lamarca, M. (2020). Real estate crisis resolution regimes and residential REITs: emerging socio-spatial impacts in Barcelona. *Housing Studies*, 36:1407 – 1426.

Geels, F. W. (2018). Low-carbon transition via system reconfiguration? A socio-technical whole system analysis of passenger mobility in Great Britain (1990–2016). *Energy Research & Social Science*, 46:86–102.

Geels, F. W. (2019). Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, 39:187–201.

Geurs, K. T. and van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, 12(2):127–140.

Giannotti, M., Barros, J., Tomasiello, D. B., Smith, D., Pizzol, B., Santos, B. M., Zhong, C., Shen, Y., Marques, E., and Batty, M. (2021). Inequalities in transit accessibility: Contributions from a comparative study between Global South and North metropolitan regions. *Cities*, 109:103016.

Giannotti, M., Tomasiello, D. B., and Bittencourt, T. A. (2022). The bias in estimating accessibility inequalities using gravity-based metrics. *Journal of Transport Geography*, 101:103337.

Goldthorpe, J. H. and Jackson, M. (2007). Intergenerational class mobility in contemporary Britain: political concerns and empirical findings. *The British Journal of Sociology*, 58(4):525–546. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1468-4446.2007.00165.x.

Golub, A. and Martens, K. (2014). Using principles of justice to assess the modal equity of regional transportation plans. *Journal of Transport Geography*, 41:10–20.

Goodman, A. and Cheshire, J. (2014). Inequalities in the London bicycle sharing system revisited: Impacts of extending the scheme to poorer areas but then doubling prices. *Journal of Transport Geography*, 41:272–279.

Graham, M. and Dittus, M. (2022). *Geographies of Digital Exclusion: Data and Inequality*. Pluto Press, London.

Graham, S. and Marvin, S. (2001). *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition*. Routledge, London.

Grengs, J., Levine, J., Shen, Q., and Shen, Q. (2010). Intermetropolitan Comparison of Transportation Accessibility: Sorting Out Mobility and Proximity in San Francisco and Washington, D.C. 29(4):427–443.

Guerrero, O. A. (2020). Decentralized markets and the emergence of housing wealth inequality. *Computers, Environment and Urban Systems*, 84:101541.

Guidetti, G. and Rehbein, B. (2014). Theoretical Approaches to Inequality in Economics and Sociology. A Preliminary Assessment. 5(1).

Guo, C., Buchmann, C., and Schwarz, N. (2019). Linking urban sprawl and income segregation – Findings from a stylized agent-based model. *Environment and Planning B: Urban Analytics and City Science*, 46(3):469–489.

Guo, Y., Zhu, J., and Liu, X. (2018). Implication of rural urbanization with place-based entitlement for social inequality in China. *Cities*, 82:77–85.

Guzman, L. A. and Hessel, P. (2022). The effects of public transport subsidies for lower-income users on public transport use: A quasi-experimental study. *Transport Policy*, 126:215–224.

Géron, A. (2017). *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 2nd Edition [Book]*. O'Reilly Media, Inc. ISBN: 9781492032649.

Hansen, W. G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*, 25(2):73–76. Publisher: Routledge _eprint: https://doi.org/10.1080/01944365908978307.

Harding, A. and Blokland, T. (2014). *Urban Theory A critical introduction to power, cities and urbanism in the 21st century*. SAGE Publications Ltd.

Harvey, D. (2003). The right to the city. *International Journal of Urban and Regional Research*, 27(4):939–941. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.0309-1317.2003.00492.x.

Harvey, D. (2005). *A Brief History of Neoliberalism*. Oxford University Press, Oxford.

Harvey, D. (2008). The Right to the City. *New Left Review*, (53):23–40.

Harvey, D. (2009). *Social Justice and the City*. University of Georgia Press. Google-Books-ID: GJMFBAAAQBAJ.

Harvey, D. (2019). *Rebel Cities: From the Right to the City to the Urban Revolution*. Verso Books. Pages: 208.

Hermans, L. M. and Thissen, W. A. H. (2009). Actor analysis methods and their use for public policy analysts. *European Journal of Operational Research*, 196(2):808–818.

Hey, T., Tansley, S., Tolle, K., and Gray, J. (2009). The Fourth Paradigm: Data-Intensive Scientific Discovery.

Hillier, B. (1999). The Hidden Geometry of Deformed Grids: Or, Why Space Syntax Works, When it Looks as Though it Shouldn't. *Environment and Planning B: Planning and Design*, 26(2):169–191.

Hillier, B. and Hanson, J. (1984). *The Social Logic of Space*. Cambridge University Press, Cambridge.

Hillier, B. and Netto, V. (2002). Society seen through the prism of space: outline of a theory of society and space. *URBAN DESIGN International*, 7(3-4):181–203.

Hochstenbach, C. (2018). Spatializing the intergenerational transmission of inequalities: Parental wealth, residential segregation, and urban inequality. *Environment and Planning A: Economy and Space*, 50(3):689–708. Publisher: SAGE Publications Ltd.

Hochstenbach, C. and Arundel, R. (2019). Spatial housing market polarisation: National and urban dynamics of diverging house values. *Transactions of the Institute of British Geographers*, null:null.

Hochstenbach, C. and Ronald, R. (2020). The unlikely revival of private renting in Amsterdam: Re-regulating a regulated housing market. *Environment and Planning A: Economy and Space*, 52(8):1622–1642. Publisher: SAGE Publications Ltd.

Hochstenbach, C., Wind, B. J., and Arundel, R. (2020). Resurgent landlordism in a student city: urban dynamics of private rental growth. *Urban Geography*, 42:769 – 791.

Huang, Y. and Jiang, L. (2009). Housing Inequality in Transitional Beijing. *International Journal of Urban and Regional Research*, 33(4):936–956. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1468-2427.2009.00890.x.

Hudson, R. (2013). Thatcherism and its geographical legacies: The new map of socio-spatial inequality in the Divided Kingdom. *Geographical Journal*, 179(4):377–381.

Jackson, J., Forest, B., and Sengupta, R. (2008). Agent-Based Simulation of Urban Residential Dynamics and Land Rent Change in a Gentrifying Area of Boston. *Transactions in GIS*, 12(4):475–491. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/j.1467-9671.2008.01109.x.

Jacobs, J. (2012). Commentary—Comparing Comparative Urbanisms. ISSN: 0272-3638.

Jacobs, R. (2022). Institutional barriers to an intermodal integrated public transport system in the City of Cape Town. Master's thesis, University of Cape Town.

James, L., Daniel, L., Bentley, R., and Baker, E. (2022). Housing inequality: a systematic scoping review. *Housing Studies*, 0(0):1–22. Publisher: Routledge _eprint: https://doi.org/10.1080/02673037.2022.2119211.

Jünger, S. (2022). Land use disadvantages in Germany: A matter of ethnic income inequalities? *Urban Studies*, 59(9):1819–1836. Publisher: SAGE Publications Ltd.

Kandt, J. and Batty, M. (2021). Smart cities, big data and urban policy: Towards urban analytics for the long run. *Cities*, 109:102992.

Kang, W., Rey, S., Wolf, L., Knaap, E., and Han, S. (2020). Sensitivity of sequence methods in the study of neighborhood change in the United States. *Computers, Environment and Urban Systems*, 81:101480.

Karimi, K. and Chen, P. N. (2022). *Multilevel Multimodal Network Modelling The Spatial Impacts of The Public Transport on Urban Systems.*

Karner, A., Pereira, R. H. M., and Farber, S. (2023). Advances and pitfalls in measuring transportation equity. Publisher: OSF.

Kawata, K. and Sato, Y. (2012). On-the-job search in urban areas. *Regional Science and Urban Economics*, 42(4):715–726.

Kenis, P. and Schneider, V. (1991). Policy networks and policy analysis: Scrutinizing a new analytical toolbox. In Marin, B. and Mayntz, R., editors, *Policy networks*, pages 25–59. Westview Press, Boulder, Colorado.

Kerr, G. (2016). 'Predistribution', property-owning democracy and land value taxation. *Politics, Philosophy & Economics*, 15(1):67–91. Publisher: SAGE Publications.

Kitchin, R. (2014). Big Data, new epistemologies and paradigm shifts. *Big Data & Society*, 1(1):2053951714528481. Publisher: SAGE Publications Ltd.

Kitchin, R., Lauriault, T. P., and McArdle, G. (2015). Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards. *Regional Studies, Regional Science*, 2(1):6–28. Publisher: Routledge _eprint: https://doi.org/10.1080/21681376.2014.983149.

Knott, E., Rao, A. H., Summers, K., and Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, 2(1):1–15. Number: 1 Publisher: Nature Publishing Group.

Kolb, K., Skopek, N., and Blossfeld, H.-P. (2013). The two dimensions of housing inequality in Europe are high home ownership rates an indicator of low housing values? [Zwei Dimensionen der Wohneigentumsungleichheit in Europa Sind hohe Wohneigentumsquoten ein Indiz für niedrige Immobilienwerte?]. *Comparative Population Studies*, 38(4):1009–1041.

Kombe, W. J., P, N., Jagadeesh, K., and Raj, A. (2022). The State of inequalities in Sub-Saharan African and Asian cities.

Kuyvenhoven, J. and Boterman, W. R. (2021). Neighbourhood and school effects on educational inequalities in the transition from primary to secondary education in Amsterdam. *Urban Studies*, 58(13):2660–2682. Publisher: SAGE Publications Ltd.

Kuznets, S. (1955). Economic Growth and Income Inequality. *The American Economic Review*, 45(1):1–28. Publisher: American Economic Association.

Lage, J., Thema, J., Zell-Ziegler, C., Best, B., Cordroch, L., and Wiese, F. (2023). Citizens call for sufficiency and regulation — A comparison of European citizen assemblies and National Energy and Climate Plans. *Energy Research & Social Science*, 104:103254.

Lauwerier, R., Wever, E., and Colenbrander, S. (2017). Evaluatie toepassing artikel 8 Rotterdamwet.

Lee, K. O., Smith, R., and Galster, G. (2017). Neighborhood trajectories of low-income U.S. households: An application of sequence analysis. *Journal of Urban Affairs*, 39(3):335–357. Publisher: Routledge _eprint: https://doi.org/10.1080/07352166.2016.1251154.

Lefebvre, H. (1968). *The Right to the City*. Economica, Paris.

Lesnard, L. (2010). Setting Cost in Optimal Matching to Uncover Contemporaneous Socio-Temporal Patterns. *Sociological Methods & Research*, 38(3):389–419. Publisher: SAGE Publications Inc.

Levinson, D. M. (1998). Accessibility and the journey to work. *Journal of Transport Geography*, 6(1):11–21.

Lewis, E. O., MacKenzie, D., and Kaminsky, J. (2021). Exploring equity: How equity norms have been applied implicitly and explicitly in transportation research and practice. *Transportation Research Interdisciplinary Perspectives*, 9:100332.

Li, H., Herfort, B., Lautenbach, S., Chen, J., and Zipf, A. (2022). Improving OpenStreetMap missing building detection using few-shot transfer learning in sub-Saharan Africa. *Transactions in GIS*, 26(8):3125–3146. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/tgis.12941.

Li, H., Wei, Y. D., and Swerts, E. (2020). Spatial inequality in the city-regions in the Yangtze River Valley, China. *Urban Studies*, 57(3):672–689. Publisher: SAGE Publications Ltd.

Lin, K.-H. and Polsky, C. (2016). Indexing livelihood vulnerability to the effects of typhoons in indigenous communities in Taiwan. *Geographical Journal*, 182(2):135–152.

Litman, T. (2022). Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transport Planning. *ITE Journal*, 92(4):44–49.

Liu, C. and Duan, D. (2020). Spatial inequality of bus transit dependence on urban streets and its relationships with socioeconomic intensities: A tale of two megacities in China. *Journal of Transport Geography*, 86.

Liu, C. and O'Sullivan, D. (2016). An abstract model of gentrification as a spatially contagious succession process. *Computers, Environment and Urban Systems*, 59:1–10.

Liu, L., Zhang, M., and Xu, T. (2020). A conceptual framework and implementation tool for land use planning for corridor transit oriented development. *Cities*, 107:102939.

Liu, T., Cats, O., and Gkiotsalitis, K. (2021). A review of public transport transfer coordination at the tactical planning phase. *Transportation Research Part C: Emerging Technologies*, 133:103450.

Lloyd, C. D., Bhatti, S., McLennan, D., Noble, M., and Mans, G. (2021). Neighbourhood change and spatial inequalities in Cape Town. *The Geographical Journal*, 187(4):315–330. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/geoj.12400.

Logan, T. M., Anderson, M. J., Williams, T. G., and Conrow, L. (2021). Measuring inequalities in urban systems: An approach for evaluating the distribution of amenities and burdens. *Computers, Environment and Urban Systems*, 86:101590.

Lope, D. and Dolgun, A. (2020). Measuring the inequality of accessible trams in Melbourne. *Journal of Transport Geography*, 83.

Lowies, B., Squires, G., Rossini, P., and McGreal, S. (2022). Locked-out: generational inequalities of housing tenure and housing type. *Property Management*, 40(4):510–526.

Lubell, J. (2016). Preserving and Expanding Affordability in Neighborhoods Experiencing Rising Rents and Property Values. *Cityscape*, 18(3):131–150. Publisher: US Department of Housing and Urban Development.

Lucas, K. (2012). Transport and social exclusion: Where are we now? *Transport Policy*, 20:105–113.

Lucas, K., van Wee, B., and Maat, K. (2016). A method to evaluate equitable accessibility: combining ethical theories and accessibility-based approaches. *Transportation*, 43(3):473–490.

Luo, D., Cats, O., Lint, J., and Currie, G. (2019). Integrating network science and public transport accessibility analysis for comparative assessment. *Journal of Transport Geography*, 80:102505.

Luo, H. and Zhao, S. (2021). Impacts of high-speed rail on the inequality of intercity accessibility: A case study of Liaoning Province, China. *Journal of Transport Geography*, 90.

Luo, W. and Wang, F. (2003). Measures of Spatial Accessibility to Health Care in a GIS Environment: Synthesis and a Case Study in the Chicago Region. *Environment and Planning B: Planning and Design*, 30(6):865–884. Publisher: SAGE Publications Ltd STM.

Lyons, G., Bristol, U., MacDonald, M., Cragg, S., and Neil, M. (2018). Embracing uncertainty and shaping transport for Scotland's future.

Lyons, G., Rohr, C., Smith, A., Rothnie, A., and Curry, A. (2021). Scenario planning for transport practitioners. *Transportation Research Interdisciplinary Perspectives*, 11:100438.

Machiels, T., Goodspeed, R., Compernolle, T., and Coppens, T. (2023). Creating Flexible Plans for an Uncertain Future: From Exploratory Scenarios to Adaptive Plans With Real Options. *Planning Theory & Practice*, 24(3):366–385. Publisher: Routledge _eprint: https://doi.org/10.1080/14649357.2023.2220701.

Madden, D. (2025). Social Reproduction and the Housing Question. *Antipode*, 57(2):578–598. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/anti.13132.

Madden, D. and Marcuse, P. (2016). *In Defense of Housing: The Politics of Crisis*. Verso Books. Pages: 240.

Mahmoudi, D., Lubitow, A., and Christensen, M. A. (2020). Reproducing spatial inequality? The sustainability fix and barriers to urban mobility in Portland, Oregon. *Urban Geography*, 41(6):801–822.

Malpass, P. (2008). Housing and the New Welfare State: Wobbly Pillar or Cornerstone? *Housing Studies*, 23(1):1–19.

Mandelker, D. R. (2023). Zoning for Mixed-Use Development.

Manley, D., van Ham, M., and Doherty, J. (2011). Social Mixing as a Cure for Negative Neighbourhood Effects: Evidence Based Policy or Urban Myth? *The Institute for the Study of Labor*, page 19.

Manson, S. and O'Sullivan, D. (2006). Complexity Theory in the Study of Space and Place. *Environment and Planning A: Economy and Space*, 38(4):677–692.

Marsh, B., Parnell, A., and Joyner, A. (2010). Institutionalization of racial inequality in local political geographies. *Urban Geography*, 31(5):691–709.

Martens, K. (2017). *Transport Justice: Designing fair transportation systems*. Routledge, New York.

Martens, K., Golub, A., and Robinson, G. (2012). A justice-theoretic approach to the distribution of transportation benefits: Implications for transportation planning practice in the United States. *World Transit Research*.

Martínez, C., Hodgson, F., Mullen, C., and Timms, P. (2018). Creating inequality in accessibility: The relationships between public transport and social housing policy in deprived areas of Santiago de Chile. *Journal of Transport Geography*, 67:102–109.

Massey, D. (2005). *For Space*. SAGE Publications Ltd, London, UK.

Mayaud, J. R., Tran, M., and Nuttall, R. (2019). An urban data framework for assessing equity in cities: Comparing accessibility to healthcare facilities in Cascadia. *Computers, Environment and Urban Systems*, 78:101401.

Mayock, T. and Malacrida, R. (2018). Socioeconomic and racial disparities in the financial returns to homeownership. *Regional Science and Urban Economics*, 70:80–96.

Mccartney, S. and Stittle, J. (2013). 'Failing to deliver'—the privatized British rail freight industry. *Public Money & Management*, 33.

McPhearson, T., Haase, D., Kabisch, N., and Gren, (2016). Advancing understanding of the complex nature of urban systems. *Ecological Indicators*, 70:566–573.

Medina, R., Byrne, K., Brewer, S., and Nicolosi, E. (2020a). Corrigendum to "Housing inequalities: Eviction patterns in Salt Lake County, Utah" [Cities 104 (2020) 102804] (Cities (2020) 104, (S0264275119305840), (10.1016/j.cities.2020.102804)). *Cities*, 107.

Medina, R. M., Byrne, K., Brewer, S., and Nicolosi, E. A. (2020b). Housing inequalities: Eviction patterns in Salt Lake County, Utah. *Cities*, 104:102804.

Meerow, S., Pajouhesh, P., and Miller, T. R. (2019). Social equity in urban resilience planning. *Local Environment*, 24(9):793–808. Publisher: Routledge _eprint: https://doi.org/10.1080/13549839.2019.1645103.

Menzies, M. and Middleton, L. (2020). Using Scenarios in Public Policy. *Policy Quarterly*, 16(2). Number: 2.

Messina, J. P., Evans, T. P., Manson, S. M., Shortridge, A. M., Deadman, P. J., and Verburg, P. H. (2008). Complex systems models and the management of error and uncertainty. *Journal of Land Use Science*, 3(1):11–25. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/17474230802047989.

Metz, N. and Burdina, M. (2018). Neighbourhood income inequality and property crime. *Urban Studies*, 55(1):133–150.

Mezaroş, M. and Paccoud, A. (2022). Accelerating housing inequality: property investors and the changing structure of property ownership in Luxembourg. *International Journal of Housing Policy*.

Milanovic, B. (2005). *Worlds Apart: Measuring International and Global Inequality*. Princeton University Press.

Milanovic, B. (2016). *Global Inequality: A New Approach for the Age of Globalization*. Harvard University Press.

Modai-Snir, T. and van Ham, M. (2018). Neighbourhood change and spatial polarization: The roles of increasing inequality and divergent urban development. *Cities*, 82:108–118.

Modai-Snir, T. and van Ham, M. (2020). Reordering, inequality and divergent growth: processes of neighbourhood change in Dutch cities. *Regional Studies*, 54(12):1668–1679. Publisher: Routledge _eprint: https://doi.org/10.1080/00343404.2020.1747607.

Modai Snir-Snir, T. and van Ham, M. (2018). Inequality, Reordering and Divergent Growth: Processes of Neighbourhood Change in Dutch Cities. *Inequality, Reordering and Divergent Growth*. Place: Bonn Publisher: Forschungsinstitut zur Zukunft der Arbeit/ Institute for the Study of Labor (IZA).

Molar-Cruz, A., Pöhler, L., Hamacher, T., and Diepold, K. (2022). Who settles where? Simulating urban growth and socioeconomic level using cellular automata and random forest regression. *Environment and Planning B: Urban Analytics and City Science*.

Moreno, C., Allam, Z., Chabaud, D., Gall, C., and Pratlong, F. (2021). Introducing the "15-Minute City": Sustainability, Resilience and Place Identity in Future Post-Pandemic Cities. *Smart Cities*, 4(1):93–111. Number: 1 Publisher: Multidisciplinary Digital Publishing Institute.

Moreno-Monroy, A., Lovelace, R., and Ramos, F. (2018). Public transport and school location impacts on educational inequalities: Insights from São Paulo. *Journal of Transport Geography*, 67:110–118.

Morris, J. M., Dumble, P. L., and Wigan, M. R. (1979). Accessibility indicators for transport planning. *Transportation Research Part A: General*, 13(2):91–109.

Morrison, E. J. (2022). Unbundling, Markets, and Regulation. In *The Palgrave Handbook of International Energy Economics*, pages 471–491. Palgrave Macmillan, Cham.

Mulder, C. H. (2021). Key note presentation The relationship between population and housing.

Musterd, S., Hochstenbach, C., and Boterman, W. (2020). Ripples of structural economic transformation: The changing social geographies of Dutch metropolitan regions. *Applied Geography*, null:null.

Musterd, S., Marcińczak, S., van Ham, M., and Tammaru, T. (2017). Socioeconomic segregation in European capital cities. Increasing separation between poor and rich. *Urban Geography*, 38(7):1062–1083. Publisher: Routledge _eprint: https://doi.org/10.1080/02723638.2016.1228371.

Musterd, S. and Ostendorf, W. (2021). Urban renewal policies in the Netherlands in an era of changing welfare regimes. *Urban Research & Practice*, 0(0):1–17. Publisher: Routledge _eprint: https://doi.org/10.1080/17535069.2021.1983861.

Myers, G. (2011). *African Cities: Alternative Visions of Urban Theory and Practice.*, volume 37. Zed Books, London ; New York. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2427.12072_5.

Nations, U. (2018). World Urbanization Prospects.

Nelson, R., Warnier, M., and Verma, T. (2024a). Conceptualizing Urban Inequalities as a Complex Socio-Technical Phenomenon. *Geographical Analysis*, 56(2):187–216. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/gean.12373.

Nelson, R., Warnier, M., and Verma, T. (2024b). Housing inequalities: The space-time geography of housing policies. *Cities*, 145:104727.

Nelson, R., Warnier, M., and Verma, T. (2025). Ethically informed urban planning: measuring distributive spatial justice for neighbourhood accessibility. ISSN: 2693-5015.

Nelson, R. J. (2021). The spatial and social logic of the Minibus Taxi network: how access may support social inclusion in Cape Town, South Africa. *Applied Mobilities*, 0(0):1–25. Publisher: Routledge _eprint: https://doi.org/10.1080/23800127.2021.1926054.

Nicoletti, L., Sirenko, M., and Verma, T. (2023). Disadvantaged communities have lower access to urban infrastructure. *Environment and Planning B: Urban Analytics and City Science*, 50(3):831–849. Publisher: SAGE Publications Ltd STM.

Nieuwenhuis, J. and Hooimeijer, P. (2016). The association between neighbourhoods and educational achievement, a systematic review and meta-analysis. *Journal of housing and the built environment: HBE*, 31(2):321–347.

Nieuwenhuis, J., Tammaru, T., van Ham, M., Hedman, L., and Manley, D. (2020). Does segregation reduce socio-spatial mobility? Evidence from four European countries with different inequality and segregation contexts. *Urban Studies*, 57(1):176–197. Publisher: SAGE Publications Ltd.

Nijman, J. and Wei, Y. D. (2020). Urban inequalities in the 21st century economy. *Applied Geography*, 117:102188.

O'Neil, C. (2016). *Weapons of Math Destruction: How Big Data Increases Inequality and Threatens Democracy*. Crown.

Oviedo, D. (2021). Chapter Five - Making the links between accessibility, social and spatial inequality, and social exclusion: A framework for cities in Latin America. In Pereira, R. H. M. and Boisjoly, G., editors, *Advances in Transport Policy and Planning*, volume 8 of *Social Issues in Transport Planning*, pages 135–172. Academic Press.

Owens, A. and Candipan, J. (2019). Social and spatial inequalities of educational opportunity: A portrait of schools serving high- and low-income neighbourhoods in US metropolitan areas. *Urban Studies*, 56(15):3178–3197.

Paccoud, A. (2020). The top tail of the property wealth distribution and the production of the residential environment. *International Journal of Housing Policy*, 20:100 – 119.

Paddeu, D. and Lyons, G. (2024). Foresight through developing shared mental models: The case of Triple Access Planning. *Futures*, 155:103295.

Pan, M. M., Wong, S., Tainter, F., Woelfel, S., and Ryan, A. (2024). Integrating equity in transportation scenario planning: A systematic review. *Transport Policy*, 145:85–95.

Pappalardo, E., Zanetti, C., and Todeschi, V. (2023). Mapping urban heat islands and heat-related risk during heat waves from a climate justice perspective: A case study in the municipality of Padua (Italy) for inclusive adaptation policies. *Landscape and Urban Planning*, 238.

Parnell, S. and Pieterse, E. (2016). Translational Global Praxis: Rethinking Methods and Modes of African Urban Research. *International Journal of Urban and Regional Research*, 40(1):236–246. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2427.12278.

Parnell, S., Pieterse, E., and Watson, V. (2009). Planning for cities in the global South: an African research agenda for sustainable human settlements. *Progr Plan*, 72.

Parnell, S. and Robinson, J. (2012). (Re)theorizing Cities from the Global South: Looking Beyond Neoliberalism. *Urban Geography*, 33(4):593–617. Publisher: Routledge _eprint: https://doi.org/10.2747/0272-3638.33.4.593.

Patias, N., Rowe, F., and Arribas-Bel, D. (2021). Trajectories of neighbourhood inequality in Britain: Unpacking inter-regional socioeconomic imbalances, 19712011. *Geographical Journal*.

Patias, N., Rowe, F., and Arribas-Bel, D. (2022). Trajectories of neighbourhood inequality in Britain: Unpacking inter-regional socioeconomic imbalances, 19712011. *Geographical Journal*, 188(2):150–165.

Patorniti, N. P., Stevens, N. J., and Salmon, P. M. (2018). A sociotechnical systems approach to understand complex urban systems: A global transdisciplinary perspective. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 28(6):281–296. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/hfm.20742.

Pawson, H. and Martin, C. (2020). Rental property investment in disadvantaged areas: the means and motivations of Western Sydney's new landlords. *Housing Studies*, 36:621 – 643.

Peck, J., Theodore, N., and Brenner, N. (2009). Neoliberal Urbanism: Models, Moments, Mutations. *The SAIS Review of International Affairs*, 29(1):49–66. Publisher: The Johns Hopkins University Press.

Pereira, R. H. M. (2019). Future accessibility impacts of transport policy scenarios: Equity and sensitivity to travel time thresholds for Bus Rapid Transit expansion in Rio de Janeiro. *Journal of Transport Geography*, 74:321–332.

Pereira, R. H. M., Braga, C. K. V., Servo, L. M., Serra, B., Amaral, P., Gouveia, N., and Paez, A. (2021). Geographic access to COVID-19 healthcare in Brazil using a balanced float catchment area approach. *Social Science & Medicine*, 273:113773.

Pereira, R. H. M., Schwanen, T., and Banister, D. (2016). Distributive justice and equity in transportation. *Transport Reviews*. Publisher: Routledge.

Pereira, R. H. M., Schwanen, T., and Banister, D. (2017). Distributive justice and equity in transportation. *Transport Reviews*, 37(2):170–191. Publisher: Routledge _eprint: https://doi.org/10.1080/01441647.2016.1257660.

Peyton Young, H. (1994). *Equity | Princeton University Press*. Princeton University Press, New Jersey.

Pieterse, E. (2019). Urban governance and spatial transformation ambitions in Johannesburg. *Journal of Urban Affairs*, 41(1):20–38.

Pike, A., Béal, V., Cauchi-Duval, N., Franklin, R., Kinossian, N., Lang, T., Leibert, T., MacKinnon, D., Rousseau, M., Royer, J., Servillo, L., Tomaney, J., and Velthuis, S. (2024). 'Left behind places': a geographical etymology. *Regional Studies*, 58(6):1167–1179. Publisher: RSA Website _eprint: https://doi.org/10.1080/00343404.2023.2167972.

Piketty, T. (2014). *Capital in the Twenty-First Century*. The Belknap Press of Harvard University Press, London.

Portugali, J. (2000). *Self-organization and the city*. Springer series in synergetics, 0172-7389. Springer, Berlin ;. Section: xvii, 352 pages : illustrations ; 25 cm.

Pot, F. J., Koster, S., and Tillema, T. (2023). Perceived accessibility and residential self-selection in the Netherlands. *Journal of Transport Geography*, 108:103555.

Power, A. (2012). Social inequality, disadvantaged neighbourhoods and transport deprivation: An assessment of the historical influence of housing policies. *Journal of Transport Geography*, 21:39–48.

Reardon, S. F. and Bischoff, K. (2011). Income Inequality and Income Segregation. *American Journal of Sociology*, 116(4):1092–1153. Publisher: The University of Chicago Press.

Rehbein, B., editor (2011). *Globalization and Inequality in Emerging Societies*. Palgrave Macmillan UK, London.

Renaud, B. and Kim, K.-H. (2008). The Global Housing Price Boom and its Aftermath. page 18.

Ringland, G. (1998). *Scenario Planning Managing for the Future*. John Wiley & Sons, New York, NY.

Rittel, H. W. J. and Webber, M. M. (1973). Dilemmas in a General Theory of Planning. *Policy Sciences*, 4(2):155–169.

Robinson, C. (2019). Energy poverty and gender in England: A spatial perspective. *Geoforum*, 104:222–233.

Robinson, J. (2016). Comparative Urbanism: New Geographies and Cultures of Theorizing the Urban. *International Journal of Urban and Regional Research*, 40(1):187–199. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2427.12273.

Robinson, J. and Attuyer, K. (2021). Extracting Value, London Style: Revisiting the Role of the State in Urban Development. *International Journal of Urban and Regional Research*, 45(2):303–331. _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/1468-2427.12962.

Rocco, R., Bracken, G., Newton, C., and Dabrowski, M. (2022). *Teaching, Learning & Researching: Spatial Planning*. TU Delft OPEN Publishing.

Rodríguez-Pose, A. and Storper, M. (2020). Housing, urban growth and inequalities: The limits to deregulation and upzoning in reducing economic and spatial inequality. *Urban Studies*, 57(2):223–248. Publisher: SAGE Publications Ltd.

Rokem, J. and Vaughan, L. (2019). Geographies of ethnic segregation in Stockholm: The role of mobility and co-presence in shaping the 'diverse' city. *Urban Studies*, 56(12):2426–2446. Publisher: SAGE Publications Ltd.

Ronald, R. and Dol, K. (2011). Housing in the Netherlands before and after the global financial crisis. *Housing Markets and the Global Financial Crisis: The Uneven Impact on Households*, pages 93–112.

Ronald, R. and Kadi, J. (2018). The Revival of Private Landlords in Britain's Post-Homeownership Society. *New Political Economy*, 23:786 – 803.

Ronald, R. and Lennartz, C. (2018). Housing careers, intergenerational support and family relations. *Housing Studies*, 33(2):147–159.

Ronald, R., Lennartz, C., and Kadi, J. (2017). What ever happened to asset-based welfare? Shifting approaches to housing wealth and welfare security. *Policy and politics*, 45:173–193.

Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics*, 20:53–65.

Roy, D., Lees, M. H., Pfeffer, K., and Sloot, P. M. A. (2018). Spatial segregation, inequality, and opportunity bias in the slums of Bengaluru. *Cities*, 74:269–276.

Ryan-Collins, J. (2021). Breaking the housing–finance cycle: Macroeconomic policy reforms for more affordable homes. *Environment and Planning A*, 53(3):480–502.

Rüttenauer, T. (2019). Bringing urban space back in: A multilevel analysis of environmental inequality in Germany. *Urban Studies*, 56(12):2549–2567.

SACN (2016). State of South African Cities Report. Technical report, South African Cities Network, Johannesburg.

Sampson, R. J. (2019). Neighbourhood effects and beyond: Explaining the paradoxes of inequality in the changing American metropolis. *Urban Studies*, 56(1):3–32. Publisher: SAGE Publications Ltd.

Sampson, R. J. and Winter, A. S. (2016). The Racial ecology of lead poisoning: Toxic Inequality in Chicago Neighborhoods, 1995-2013. *Du Bois Review: Social Science Research on Race*, 13(2):261–283. Publisher: Cambridge University Press.

Sandel, M. (2010). *Justice: Whats the Right thing to do?* Penguin Books, London ; New York.

Sassen, S. (2014). *Expulsions: Brutality and Complexity in the Global Economy*. Yale University Press, New York.

Scarpa, S. (2015). The impact of income inequality on economic residential segregation: The case of Malmö, 1991–2010. *Urban Studies*, 52(5):906–922.

Schmitt, S.-M. and Hartmann, T. (2016). Clumsy city by design—A theory for jane jacobs' imperfect cities? *Urban Planning*, 1(4):42–50.

Scholten, P. (2016). Between National Models and Multi-Level Decoupling: The Pursuit of Multi-Level Governance in Dutch and UK Policies Towards Migrant Incorporation. *Journal of International Migration and Integration*, 17(4):973–994. Num Pages: 973-994 Place: Dordrecht, Netherlands Publisher: Springer Nature B.V.

Sen, A. (1992). *Inequality Reexamined*. Clarendon Press.

Sen, A. (1999). *Commodities and Capabilities*. Oxford University Press. ISBN: 9780195650389.

Sen, A. (2006). What Do We Want from a Theory of Justice? *The Journal of Philosophy*, 103(5):215–238. Publisher: Journal of Philosophy, Inc.

Sevtsuk, A. and Mekonnen, M. (2012). Urban network analysis. A new toolbox for ArcGIS. *Revue internationale de géomatique*, 22(2):287–305.

Shaheen, S., Camel, M., and Lee, K. (2013). Exploring the Future of Integrated Transportation Systems in the United States from 2030 to 2050: Application of a Scenario Planning Tool.

Sharp, G. and Hall, M. (2014). Emerging forms of racial inequality in homeownership exit, 1968-2009. *Social Problems*, 61(3):427–447.

Sheller, M. (2017). From spatial turn to mobilities turn. *Current Sociology*, 65(4):623–639.

Shelton, T. and Poorthuis, A. (2019). The Nature of Neighborhoods: Using Big Data to Rethink the Geographies of Atlanta's Neighborhood Planning Unit System. *Annals of the American Association of Geographers*, 109(5):1341–1361. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/24694452.2019.1571895.

Shelton, T., Poorthuis, A., and Zook, M. (2015). Social media and the city: Rethinking urban socio-spatial inequality using user-generated geographic information. *Landscape and Urban Planning*, 142:198–211.

Silva, C., Bertolini, L., te Brömmelstroet, M., Milakis, D., and Papa, E. (2017). Accessibility instruments in planning practice: Bridging the implementation gap. *Transport Policy*, 53:135–145.

Singleton, A., Alexiou, A., and Savani, R. (2020). Mapping the geodemographics of digital inequality in Great Britain: An integration of machine learning into small area estimation. *Computers, Environment and Urban Systems*, 82:101486.

Singleton, A. and Arribas-Bel, D. (2019). Geographic Data Science. *Geographical Analysis*, 53.

Singleton, A. D. and Longley, P. A. (2009). Geodemographics, visualisation, and social networks in applied geography. *Applied Geography*, 29(3):289–298.

Slovic, A. D., Tomasiello, D. B., Giannotti, M., Andrade, M. d. F., and Nardocci, A. C. (2019). The long road to achieving equity: Job accessibility restrictions and overlapping inequalities in the city of São Paulo. *Journal of Transport Geography*, 78:181–193.

Smith, A. (2007). *The Wealth of Nations*. Harriman House, New York.

Smith, D., Shen, Y., Barros, J., Zhong, C., Batty, M., and Giannotti, M. (2020). A compact city for the wealthy? Employment accessibility inequalities between occupational classes in the London metropolitan region 2011. *Journal of Transport Geography*, 86.

Smith, R. W., Bertolaccini, K., and Lownes, N. E. (2021). Improving transit access measures in affordable housing funding criteria. *Transport Policy*, 106:239–248.

Smith, S. J., Clark, W. A. V., Ong ViforJ, R., Wood, G. A., Lisowski, W., and Truong, N. T. K. (2022). Housing and economic inequality in the long run: The retreat of owner occupation. *Economy and Society*, 51(2):161–186. Publisher: Routledge _eprint: https://doi.org/10.1080/03085147.2021.2003086.

Soja, E. (2010). *Seeking Spatial Justice*. University of Minnesota Press, New York.

SPLUMA (2013). Spatial Planning and Land Use Management Act.

Su, S., Li, Z., Xu, M., Cai, Z., and Weng, M. (2017). A geo-big data approach to intra-urban food deserts: Transit-varying accessibility, social inequalities, and implications for urban planning. *Habitat International*, 64:22–40.

Su, S., Zhou, H., Xu, M., Ru, H., Wang, W., and Weng, M. (2019). Auditing street walkability and associated social inequalities for planning implications. *Journal of Transport Geography*, 74:62–76.

Suss, J. H. (2023). Measuring local, salient economic inequality in the UK. *Environment and Planning A: Economy and Space*. Publisher: SAGE PublicationsSage UK: London, England.

Tomasiello, D., Giannotti, M., and Feitosa, F. (2020). ACCESS: An agent-based model to explore job accessibility inequalities. *Computers, Environment and Urban Systems*, 81.

Tonkiss, F. (2020). City government and urban inequalities. *City*, 24(1-2):286–301. Publisher: RSA Website _eprint: https://doi.org/10.1080/13604813.2020.1739931.

Tori, S., de Séjournet, A., and Macharis, C. (2023). Reactions of the public transport sector to the COVID-19 pandemic. Insights from Belgium. *Travel Behaviour and Society*, 31:244–253.

Tosh-Mlambo, Y. (2024). *Exploring The Role of Social Reproductive Labour in The Taxi Industry*. PhD thesis.

Troost, A. A., Ham, M. v., and Manley, D. J. (2023). Neighbourhood effects on educational attainment. What matters more: Exposure to poverty or exposure to affluence? *PLOS One*, 18(3):e0281928. Publisher: Public Library of Science.

Tseng, C.-P. and Penning-Rowsell, E. (2012). Micro-political and related barriers to stakeholder engagement in flood risk management. *Geographical Journal*, 178(3):253–269.

Turok, I. (2001). Persistent Polarisation Post-Apartheid? Progress towards Urban Integration in Cape Town. *Urban Studies*, 38(13):2349–2377. Publisher: SAGE Publications Ltd.

Tóth, G., Wachs, J., Di Clemente, R., Jakobi, , Ságvári, B., Kertész, J., and Lengyel, B. (2021). Inequality is rising where social network segregation interacts with urban topology. *Nature Communications*, 12(1):1143. Number: 1 Publisher: Nature Publishing Group.

UN-Habitat (2021). Shaping Co-creation & Collaboration in Smart Cities: A playbook for local and regional governments.

Valenzuela Aguilera, A. and Tsenkova, S. (2019). Build it and they will come: whatever happened to social housing in Mexico. *Urban Research & Practice*, 12(4):493–504. Publisher: Routledge _eprint: https://doi.org/10.1080/17535069.2019.1623558.

van Gent, W. and Hochstenbach, C. (2020). The neo-liberal politics and socio-spatial implications of Dutch post-crisis social housing policies. *International Journal of Housing Policy*, 20(1):156–172.

van Gent, W., Hochstenbach, C., and Uitermark, J. (2018). Exclusion as urban policy: The Dutch 'Act on Extraordinary Measures for Urban Problems'. *Urban Studies*, 55(11):2337–2353. Publisher: SAGE Publications Ltd.

van Gent, W. and Musterd, S. (2016). Class, migrants, and the European city: spatial impacts of structural changes in early twenty-first century Amsterdam. *Journal of Ethnic and Migration Studies*, 42(6):893–912. Publisher: Routledge _eprint: https://doi.org/10.1080/1369183X.2015.1126092.

Van Wee, B. and Geurs, K. (2011). Discussing Equity and Social Exclusion in Accessibility Evaluations. *European Journal of Transport and Infrastructure Research*, 11(4). Number: 4.

Van Wee, B. and Mouter, N. (2021). Evaluating transport equity. In *New Methods, Reflections and Application Domains in Transport Appraisal*, volume 7, pages 103–126. Elsevier Series Advances in Transport Policy and Planning.

Van Zandt, S. and Mhatre, P. (2009). Growing pains: Perpetuating inequality through the production of low-income housing in the Dallas/Fort Worth Metroplex. *Urban Geography*, 30(5):490–513.

Vaughan, L. (2007). The spatial syntax of urban segregation. *Progress in Planning*, 67(3):205–294.

Vaughan, L. (2018). *Mapping Society*. UCL Press, London.

Vermeijden, B. (2001). Dutch urban renewal, transformation of the policy discourse 1960–2000. page 30.

Voas, D. and Williamson, P. (2001). Evaluating Goodness-of-Fit Measures for Synthetic Microdata. *Geographical and Environmental Modelling*, 5(2):177–200. Publisher: Routledge _eprint: https://doi.org/10.1080/13615930120086078.

Walzer, M. (1994). *Thick and Thin: Moral Argument at Home and Abroad*. University of Notre Dame Press.

Wan, N., Zou, B., and Sternberg, T. (2012). A three-step floating catchment area method for analyzing spatial access to health services. *International Journal of Geographical Information Science*, 26(6):1073–1089. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/13658816.2011.624987.

Wang, Y., Li, Y., Huang, Y., Yi, C., and Ren, J. (2020). Housing wealth inequality in China: An urban-rural comparison. *Cities*, 96.

Weber, M. (1972). *Wirtschaft und Gesellschaft: Grundriß der Verstehenden Soziologie*. Mohr Siebeck. Google-Books-ID: RWK_6TKVENcC.

Whitworth, A. (2013). Local Inequality and Crime: Exploring how Variation in the Scale of Inequality Measures Affects Relationships between Inequality and Crime. *Urban Studies*, 50(4):725–741.

Whitworth, A. (2022). Re-placing welfare neoliberalism: The neglected role of geography in neoliberal public policies. *Geographical Journal*, 188(1):2–13.

Wiechmann, T. (2008). Errors Expected — Aligning Urban Strategy with Demographic Uncertainty in Shrinking Cities†. *International Planning Studies*, 13(4):431–446. Publisher: RSA Website _eprint: https://doi.org/10.1080/13563470802519097.

Wilson, W. J. (1987). *The Truly Disadvantaged: The Inner City, the Underclass, and Public Policy, Second Edition*. University of Chicago Press, Chicago, IL.

Wind, B., Dewilde, C., and Doling, J. (2020). Secondary property ownership in Europe: contributing to asset-based welfare strategies and the 'really big trade-off'. *International Journal of Housing Policy*, 20:25 – 52.

Wind, B. and Hedman, L. (2018). The uneven distribution of capital gains in times of socio-spatial inequality: Evidence from Swedish housing pathways between 1995 and 2010. *Urban Studies*, 55(12):2721–2742. Publisher: SAGE Publications Ltd.

Wolff, J. and De Shalit, A. (2023). *City of Equals*. Oxford University Press, Oxford.

Wu, H., Avner, P., Boisjoly, G., Braga, C. K. V., El-Geneidy, A., Huang, J., Kerzhner, T., Murphy, B., Niedzielski, M. A., Pereira, R. H. M., Pritchard, J. P., Stewart, A., Wang, J., and Levinson, D. (2021). Urban access across the globe: an international comparison of different transport modes. *npj Urban Sustainability*, 1(1):1–9. Number: 1 Publisher: Nature Publishing Group.

Yap, C., Cocina, C., and Levy, C. (2021). *The Urban Dimensions of Inequality and Equality*.

Zhang, M., He, S., and Zhao, P. (2018). Revisiting inequalities in the commuting burden: Institutional constraints and job-housing relationships in Beijing. *Journal of Transport Geography*, 71:58–71.

Zhong, C., Arisona, S. M., Huang, X., Batty, M., and Schmitt, G. (2014). Detecting the dynamics of urban structure through spatial network analysis. *International Journal of Geographical Information Science*, 28(11):2178–2199. Publisher: Taylor & Francis _eprint: https://doi.org/10.1080/13658816.2014.914521.

Zhu, L. and Shi, F. (2022). Spatial and social inequalities of job accessibility in Kunshan city, China: Application of the Amap API and mobile phone signaling data. *Journal of Transport Geography*, 104:103451.

Supplementary Material

1 Chapter 3

1.1 Policy Details

1.2 Description of variables

The following section provides additional information on where each variable is sourced, processed and how any missing variables were managed, refer to Figure 1.1 for a visual representation of the distribution of variables across the cluster categories.

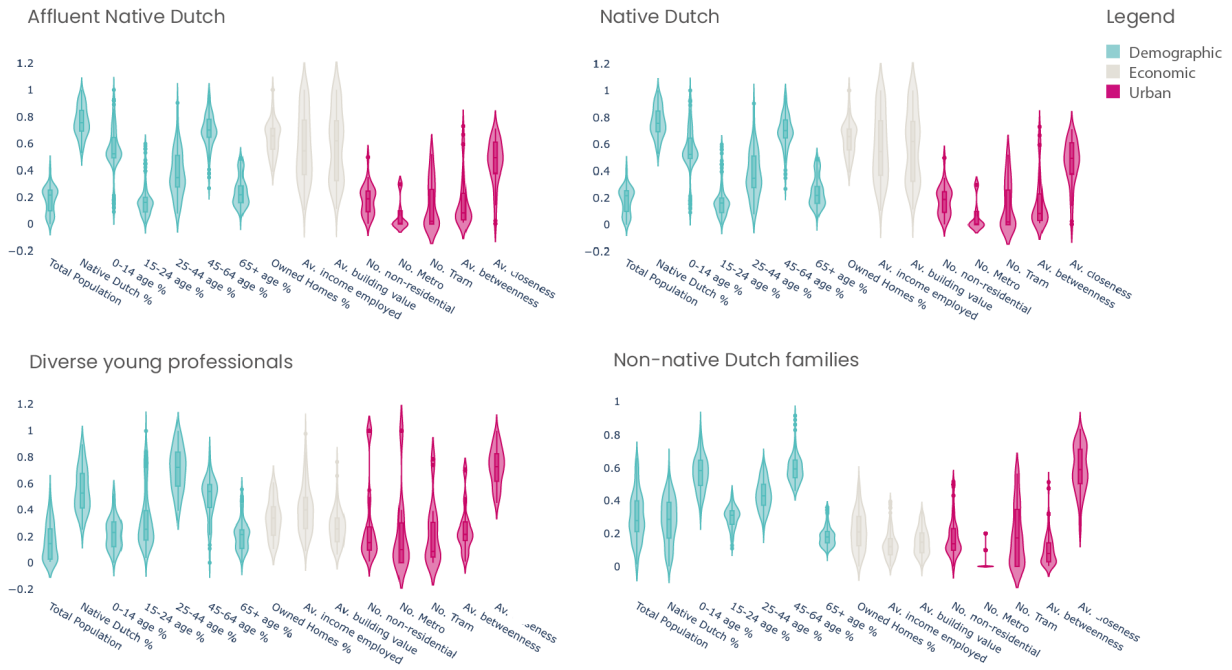

Figure 1.1: These box plots show the distributions of variables across the cluster categories.

Demographic variables

Total population

The total population is included as is an indicator of the relative size of a neighbourhood for each year. These figures are derived from the Central Bureau of Statistics (CBS) and are in absolute numbers. The decision to include a population count is based on the strong relationship between population growth and housing. On the one hand as a population grows, more housing is required and on the other hand if more housing is constructed, an increased number of people are able to reside in a specific neighbourhood (Mulder, 2021).

Native Dutch and non-native Dutch

Previous studies show that there is a relationship between increased levels of home ownership and capital gains over time in relation to native and migrant status (Kolb et al., 2013; Wind and Hedman,

Table 1: National Housing Policies

Year	Policy	Target areas	Policy instruments	Target groups	Intentions
1945	Increased funding of Housing Associations	National	Operation subsidies, construction loans, operational regulations: tender, rent control etc.	Lower & middle & middle income groups.	Alleviate the acute housing shortage after WW2
1974	Rent and Subsidy Policy	National	Housing allowances, rent control for tenants, subsidies for landlords for dwelling improvement.	Housing Associations, private landlords and tenants	Create sufficient and payable high quality dwellings.
1990	Housing in the 90's memorandum	National	This white paper gave a framework for the retreat of central gov. from housing provision.	Housing Associations, Local gov., Central gov., tenants	Creation of an institutional framework for more market driven housing.
1995	Financial Independence Housing Associations	National	Future subsidies and debts were allowed to cancel each other out, loans to be garnered directly from the Bank guaranteed by gov.	Housing Associations, Banks, Central gov.	Shift responsibility of housing to the private market.
2001	Promotion of Home Ownership Act	National	Subsidies and low interest loans for first time buyers with limits on house price and morgage.	First time buyers	Promote home ownership in low income families.
2006	Act on Extraordinary Measures for Urban Problems	Specific neighb.	Allows governments to refuse a residence permit in specific neighb. to persons who do not receive an income from work, pensions, student loans.	Low income residents	Improve quality of life in certain neighb.
2014	Landlord Levy	National	A new tax placed on incomes of the Housing Associations	Housing Associations	Reduce profits and risks of Housing Associations.
2015	Housing Act	National	Housing Associations are discouraged from providing rent-liberalised housing at least for 90% of their new	Housing middle income earners tenants.	Reduce profits and risks of Housing Associations, shift middle income earners into private market.

2018; Mezaroş and Paccoud, 2022). The percentage of native and non-native Dutch residents are derived from CBS data. In the Netherlands a resident is officially classified as non-native Dutch if they are born out of the country or are born in the country with one or both parents born outside the Netherlands.

Age groups

Recent research highlights age as an important factor when examining declining rates of home ownership (Arundel and Doling, 2017; Byrne, 2020; Hochstenbach, 2021). The percentage of residents in each neighbourhood that fall within specific age groups are included in the analysis derived from CBS data. These age groups are:

- 0 to 15 years
- 15 to 25 years
- 25 to 45 years
- 45 to 65
- 65 years or older

Table 2: Dimensions, variables and units

Dimension	Variable	Unit
Demographic	Total Population	Absolute number
	Native Dutch	Percentage
	Non-native Dutch	Percentage
	Age groups	Percentage
Economic	Mean income per person	Euro
	Mean income per working person	Euro
	Mean house value	Euro
	Unemployed persons	Percentage
	Owned units	Percentage
	Rental units	Percentage
Urban	Residential units	Absolute number
	Non-residential units	Absolute number
	Mean betweenness centrality	Real number
	Mean closeness centrality	Real number
	Tram stops	Absolute number
	Metro stops	Absolute number

Economic Variables

Income

Residential mobility patterns, home ownership levels and capital gains are shown to have a relationship with income distributions (Mayock and Malacrida, 2018) and thus indicators related to income are included as variables for consideration.

The average income per income recipient and per resident are included as indicators in Euros. For

ease of comparison, each year is adjusted for inflation up until 2018, according to rates as provided by the International Monetary Fund, which on average was 1.85% for each year between 1999 and 2018 (https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=NL) . As it was found that the income has increased in most neighbourhoods beyond rates of inflation, income was normalised for each year prior to merging all of the years together in a single data set. Therefore a neighbourhood that possesses a relatively high income in 1999, is not perceived as having a relatively low income when directly compared against income levels in 2018. This allows for insights to be gained into which neighbourhoods are relatively affluent in 1999 and have remained relatively affluent over time.

Unemployment

Employment is a factor that contributes to whether a person is able to rent, own or access social housing. Therefore it is included as a variable derived as percentage of the total neighbourhood population from CBS data.

House Value

Including the mean value of residential properties allows for insights to be gleaned into rates of capital gains over time. Every year, the value of all real estate in the Netherlands is assessed according to the Valuation of Immovable Property Act (Wet Waardering Onroerende Zaken, or WOZ). The WOZ value of a property is based on the building's characteristics, official valuations, and the selling price of nearby properties, for more information refer to: https://www.rijksoverheid.nl/onderwerpen/waardering-onroerende-zaken-woz.

The WOZ values are derived from CBS data for each neighbourhood in Euros. In 2003 the WOZ values are missing and thus the decision is made to give 2003 the same values as 2001. For ease of comparison, the WOZ values for each year are adjusted for inflation according to rates as provided by the International Monetary Fund (https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=NL). It is found that the WOZ values increased far beyond inflation and thus as with the variables related to income, the WOZ values are normalised for each year separately prior to merging the data into one data set.

Percentage of home ownership and rentals

Studying levels of home ownership across neighbourhoods over time sheds light on social mobility patterns, as owning a home is considered an important factor in building wealth and financial security (Groves et al, 2007). Owned and rental homes are recorded as a percentage of the total number of house holds in a neighbourhood by CBS. Owned homes are defined as those which are occupied by the owner or registered as a second home. Whereas, rental homes are defined as those occupied by rental tenants. Home ownership and rental data is missing data for 1999, 2001 and 2007. Thus 1999 and 2001 are imputed with data from 2003 and 2007 is imputed with 2005 data.

Urban variables

Residential and non-residential land uses

Accounting for non-residential and residential land use provides insights into the distribution of different kinds of land use diversity across neighbourhoods. The total number of residential homes on 1 January of the relevant year is included as an absolute number, derived from CBS data. A residential home is defined as a property with at least one residential function and possibly one or more other functions.

Non-residential land use refers to land use that has a business or commercial component, excluding business locations in agriculture, fisheries and hospital health care. After 2007 the total number of non-residential land use is provided in absolute numbers, but prior to 2007 companies were classified under a different system, divided into the following ordinal classes:

1. 0 to 10 business locations
2. 10 to 20 business locations
3. 20 to 50 business locations
4. 50 to 100 business locations
5. 100 to 200 business locations
6. 200 to 500 business locations
7. 500 to 1,000 business locations
8. 1000 to 2000 business locations
9. 2000 or more business locations

The land use variables before 2007 are thus transformed to an absolute number and given the median value on the ordinal scale, ie. if it possesses an ordinal value of 1 it is transformed to 5. After 2007 new kinds of businesses were included in the total count and thus it would be potentially inaccurate to compare the non-residential land uses with the differentiation in classification systems. Therefore the non-residential land use count is normalised within each year prior to merging all the data sets.

Metro and tram

The accessibility of transportation networks is associated with distributions of opportunities and socio-spatial inequalities in cities (Van wee and Geurs, 2011). The geo-location of each metro and tram stop is sourced from the South Holland Open Data Portal. Through historical records online, the implementation of each metro and tram line is recorded. Based on these dates an aggregate count of each stop and station is assigned to each neighbourhood through spatial joining.

Closeness and betweenness centralities of the street network

Closeness and betweenness centralities are measurements derived from graph theory and network analysis, which allow an understanding of the relative accessibility levels of different parts of the city to be gained, when applied to their street layouts. These are also fundamental measurements in Space Syntax, which is a set of methodologies and theories for the analysis of spatial configurations at different scales (Hillier and Hanson, 1984). *Closeness centrality*, or integration as it is called in the space syntax community, measures the reciprocal of the sum of the shortest path between every origin to every destination, in other words the "to-movement" or "destination" potential embedded within a street segment, due to its angular proximity to all other street segments within a specified radius (Freeman, 1977; Hillier and Iida, 2005). The equation for closeness centrality is as follows, where d is the shortest (topological, angular or metric) distance from a given street segment (Si) to every other street segment (Sk) in the segment map:

$$Closeness(S_i) = \frac{n-1}{\sum_{k=1}^{n} d(S_i, S_k)} \tag{1.1}$$

Betweenness, or choice as it is called in the space syntax community, is calculated by generating

shortest paths between all segments within the system (i.e., the journey with the lowest angular cost for each possible origin and destination pair of segments). The sum of the flow through each segment is calculated according to how many journeys are made through each segment and divided by the total number of possible through journeys (Freeman, 1977). The equation for betweenness centrality is as follows, where Pjk denotes the shortest paths from j to k, and Pjik the shortest paths from j to k that pass through street segment Si:

$$Betweenness(S_i) = \sum_{j=1}^{n} \sum_{k=1}^{n} \frac{P_{jik}}{P_{jk}} \tag{1.2}$$

To calculate betweenness and closeness centralities across different time periods, road centre line (RCL) networks of Rotterdam are prepared pertaining to 1995, 2005 and 2015. The road centre line networks are derived from tracing geo-located maps on QGIS from 1995, 2005 and 2015. Subsequently, the RCL networks are transformed into dual graphs in the Software, Depthmap, where every segment is a node and every connection between segments is an edge with metric cost (). In Depthmap, the closeness and betweeness metrics are computed for each graph and then the graphs are exported back to QGIS. The mean value for every neighbourhood is calculated through spatial joining to the geometric boundaries of the neighbourhoods. All data sets in between 1995 and before 2005 are assigned values from 1999, all data sets from 2005 and before 2015 are assigned values from 2005 and the 2015 and 2018 data sets are assigned values from 2015. Thus, for example, the 1999 data set is given the values of 1995 and the 2007 data set is given values from 2005.

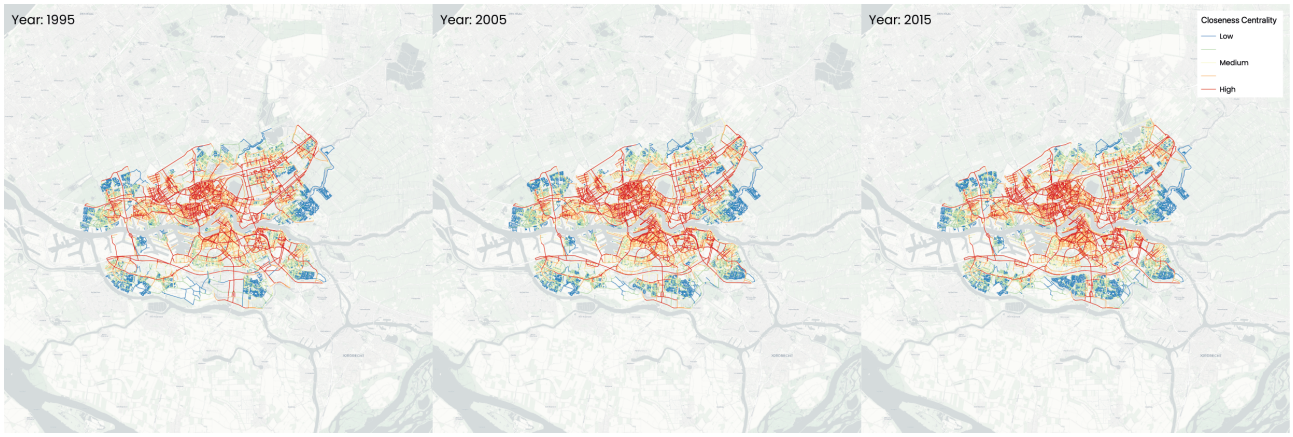

Figure 1.2: These maps show the closeness centralities of the street network. The city follows a typical radial pattern in development, with the inner core, particularly North of the River possessing high destination potential.

1.3 Normalisation of variables

The normalisation of variables enables their relative comparison across multiple dimensions and is a necessary step to prepare the data for K-means clustering. K-means clustering is a distance-based algorithm, which means that the results of clustering can be heavily influenced by the scale of the variables being used. By normalising the variables, the data are transformed into a common scale, reducing the effects of outliers and ensuring that each variable contributes equally to the clustering process, resulting in the clusters being more representative of the underlying data. The specific technique for normalisation implemented is Min-max normalization, according to the equation below, where X is the original data point, Xmin is the minimum value of X in the data set, Xmax is the maximum value of X in the data set, and Xnorm is the normalized value of X:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \tag{1.3}$$

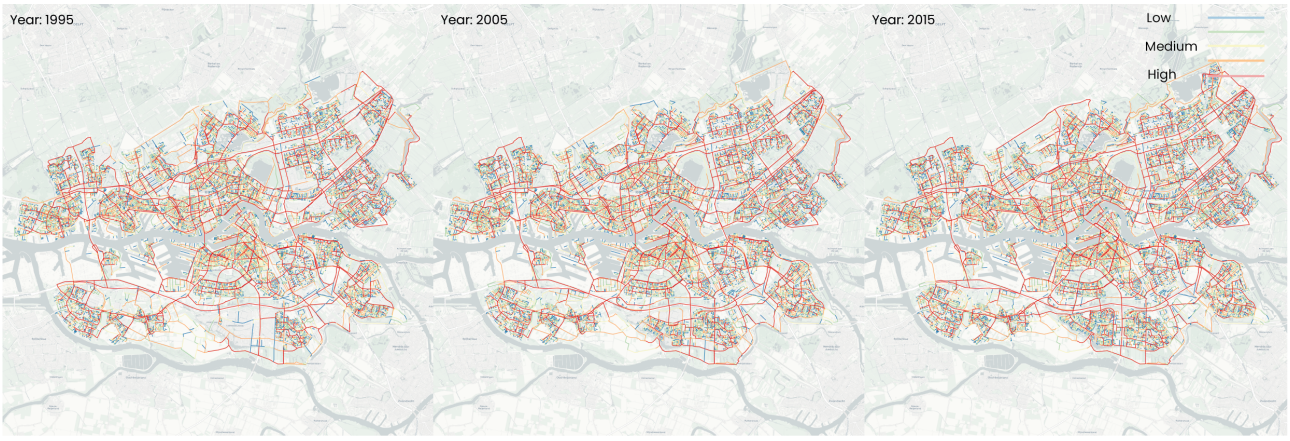

Figure 1.3: These maps display the betweenness centralities across the years. The bridges, main arterial routes and highways in the city are highlighted by this analysis.

1.4 Clustering validation

The number of clusters, k is predefined and the best k value will lead to the strongest cluster groupings. To determine the optimal k value for the clustering analyses, the *Silhouette Score* is applied (Rousseeuw, 1987). The *Silhouette Score* determines how well each data point fits into its assigned cluster, and how separated it is from other clusters, ranging from -1 to 1, with higher values indicating better cluster quality. The equation for *Silhouette Score* is as follows, with the value of the Silhouette score (Si) being determined by the difference between the the average distance between the i data point and all data points in the nearest cluster (bi) and the the average distance between the i data point and all other data points in the same cluster (ai) divided by the maximum value between ai and bi:

$$s_i = \frac{b_i - a_i}{\max(a_i, b_i)} \tag{1.4}$$

2 Chapter 4

2.1 List of Abbreviations

- CBD - Central Business District
- UNM - Urban Network Model
- NRC - Neighbourhood Reach Centrality
- NRG - Neighbourhood Reach Gap
- ERC - Equality Reach Centrality
- ERG - Equality Reach Gap
- URC - Utilitarian Reach Centrality
- URG - Utilitarian Reach Gap
- RRC - Rawls Reach Centrality
- RRG - Rawls Reach Gap
- CPT - Metropolitan Area of Cape Town

- AMM - Metropolitan Area of Monterrey
- MRDH - Metropolitan Area of Rotterdam and Den Hague
- NL - Netherlands
- MAUP - Modifiable Area Unit Problem
- BRT - Bus Rapid Transport
- INEGI - Mexican National Institute of Statistics and Geography

2.2 Transportation Appraisal Frameworks

Transportation apprasial frameworks are typically based on Cost-Benefit Analysis (CBA) or Multi-Criteria Framework (MCF). CBA in transportation appraisals is a critical tool for assessing the economic and social value of projects by comparing their total expected costs and benefits. It involves monetising costs like capital expenditure and environmental impacts, and benefits such as time savings and reduced emissions, to determine whether a project is worthwhile. Despite its utility, as the framework is based on the quantification of all variables in relation to monetary cost, other important factors such as distributional equity effects and long term sustainability considerations are difficult to incorporate and often not considered (Lucas et al., 2016).

The Multi-Criteria Analysis (MCA) in transport appraisals is an approach used to evaluate transportation projects by considering a range of criteria beyond just economic efficiency. Unlike CBA, which focuses primarily on monetary values, MCA incorporates various qualitative and quantitative factors such as environmental impact, social benefits, safety, and equity. This broader approach allows for a more comprehensive assessment of a project's overall value to society. Additionally, quantifying equity-related benefits is often difficult, making it challenging to compare them directly with more easily measured criteria like cost savings or time reductions. This can result in equity considerations being underrepresented in the final decision.

2.3 Description of the cases

The Metropolitan area of Monterrey (AMM) is an industrial and commercial centre in the North of Mexico. We have included the municipalities of Monterrey, Santa Catarina, Guadalupe, San Nicolás de los Garza, General Escobedo, Apodaca and Benito Juarez in the analysis. The urban morphology is shaped both by the surrounding Sierra Madre Oriental mountain range and also by the empty river bed which runs through the centre. The public transportation system in Monterrey primarily consists of the Ecovia Bus Rapid Transit System, the Metro system and the Bus system, which has both formal and informal components. Due to data constraints, we have only included the transportation infrastructure for the Ecovia BRT and Metro system. AMM is reported as growing from 2.6 million to 5.1 million people from 1990 to 2023 (https://www.macrotrends.net/cities/21855/monterrey/population), with many large neighbourhoods emerging on the urban periphery to accommodate this growth (Carpio et al., 2021).

Cape Town is the legislative capital of South Africa and was historically an important trading port. The Metropolitan area of Cape Town's (CPT) urban morphology was primarily shaped by the Table Mountain range, the Atlantic Ocean, and the Group Areas Act of 1951, a key piece of Apartheid legislation that classified neighbourhoods by race and created large townships, including Khayelitsha and Mitchell's Plain, on the outskirts of the cities for non-White populations. The public transportation system in CPT is predominantly composed of the MyCiti BRT, Railway, bus and para-transit minibus taxi systems. Due to data constraints, we only included the Railway and MyCiti BRT systems. As is the case with AMM, CPT has grown from 2.1 million in 1990 to 4,9 million in 2023

(https://www.macrotrends.net/cities/22481/cape-town/population), particularly in the form of informal settlements on the outskirts of the city (Turok, 2001).

The Metropolitan region of the Rotterdam and the Hague (MRDH) lies within the boundaries of the Randstad, the commercial heart of the Netherlands. The urban morphology of Rotterdam is influenced by the Maas River, which forms the largest port in Europe, whereas the North Sea limits the growth of the Hague. Whilst, the public transportation systems consist of trains, buses, trams and metro, we only included trains, trams, and the metro in our analysis. This case has three significant differences compared to the latter two. Firstly, although only neighbourhoods within the cities of Rotterdam and the Hague are examined, the boundaries of the analysis went well beyond the formal boundaries of the cities, as that is the nature of urban development in the Randstad, with different cities being very close together and generally well connected by transport. Secondly, the population growth has been far less, with the Hague growing from 604 in 1990 to 715 thousand in 2023 and Rotterdam from 951 thousand in 1990 to 1 million in 2023 (https://www.macrotrends.net/cities/21945/rotterdam/population). Finally, public transportation in this context is predominately formal.

3 Chapter 5

3.1 Theory

3.2 Stakeholder engagement

Interview questions

A total of 8 stakeholder representatives were interviewed. They represented private organisations, different levels of government and academia and were asked the following questions:

1. What is the role/function of the stakeholder?
2. What is the relationship of the stakeholder in relation to other stakeholders?
3. How satisfied is the stakeholder with current transportation and land use planning in Cape Town?
4. What actions need to be taken to improve the current systems and where does the responsibility lie?
5. What is the vision of the stakeholder for future mobility and urban development in Cape Town?
6. What are the hierarchies of objectives in that vision?
7. What are the instruments at the disposal of the stakeholder to influence their vision?
8. What timelines would be associated with that vision?
9. What are the barriers and external forces which influence success of the vision - everyday and long term.

Workshop format

The 30 participants were randomly divided into 5 Teams and over an hour were asked to deliberate over the following questions, with the aid of maps, sticky notes and paper. After the hour they were asked to present their ideas collectively to the group for discussion:

1. What are barriers to access in Cape Town and group them.

Table 3: Vertex and Edge Characteristics of each Urban Network Model

Vertex category	Vertex dimension	Description
Street vertex	Street network	Each street vertex represents an actual street intersection
BRT vertex	Transport	Each BRT vertex represents an actual BRT stop
Train vertex	Transport	Each Train vertex represents an actual Train station
Metro vertex	Transport	Each Metro vertex represents an actual Metro station
Tram vertex	Transport	Each Tram vertex represents an actual tram stop
Land use vertex	Land use	Each Land use vertex represents an actual place of employment
Created street vertex	None	This represents a point on a street that is linked to a land use or transport interchange
Edge category	**Weight**	**Description**
Street edge	varies by length of street	Connects two street intersections
Train edge	varies by route length	Connects two train stations
BRT edge	varies by route length	Connects two BRT stations
Metro edge	varies by route length	Connects two metro stations
Tram edge	varies by route length	Connects two tram stops
BRT to nearest street	0.5 min	Connects a BRT vertex with a created street vertex
Land use to nearest street	0.5 min	Connects a Land use vertex with a created street vertex
Tram to nearest street	0.5 min	Connects a tram vertex with a created street vertex
Train to nearest street	1 min	Connects a train vertex to a created street vertex

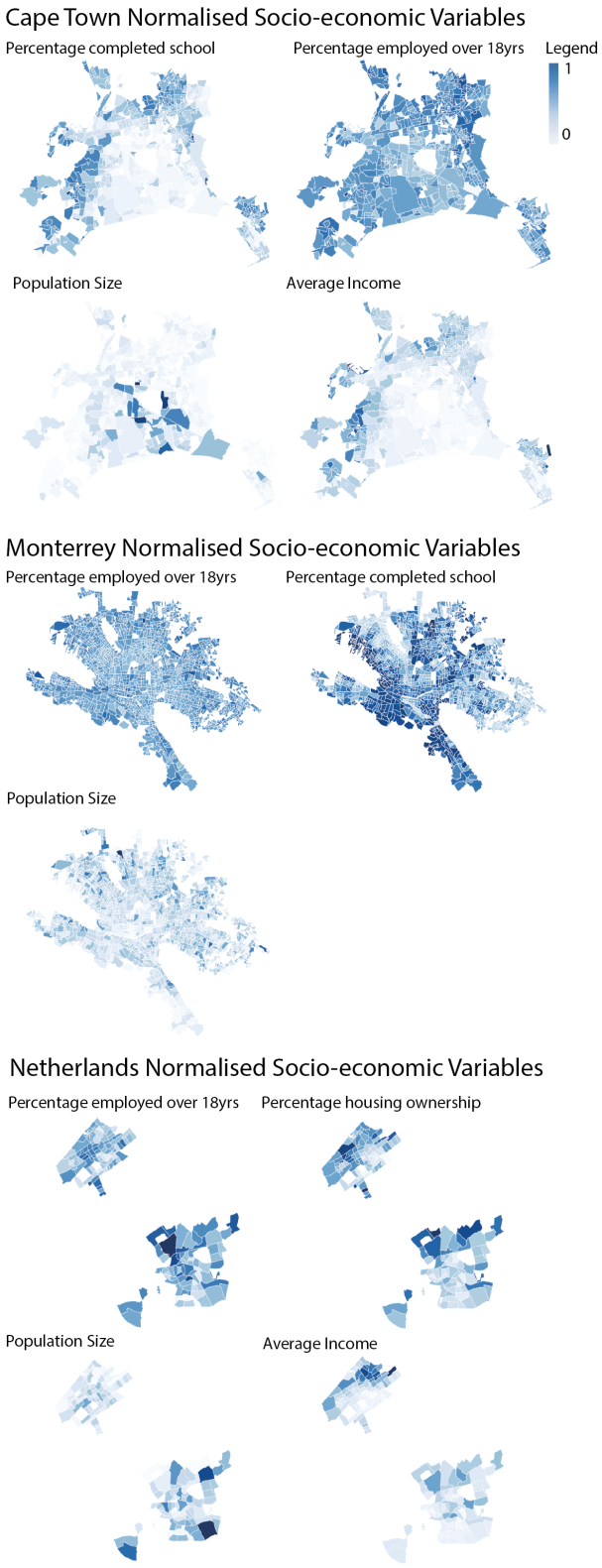

Figure 2.4: This figure visualises choropleth maps showing the distribution of key socio-economic variables in Cape Town (related to schooling, employment, population size and income), Monterrey (related to schooling, employment and population size) and Rotterdam and the Hague (related to home ownership, employment, population size and income).

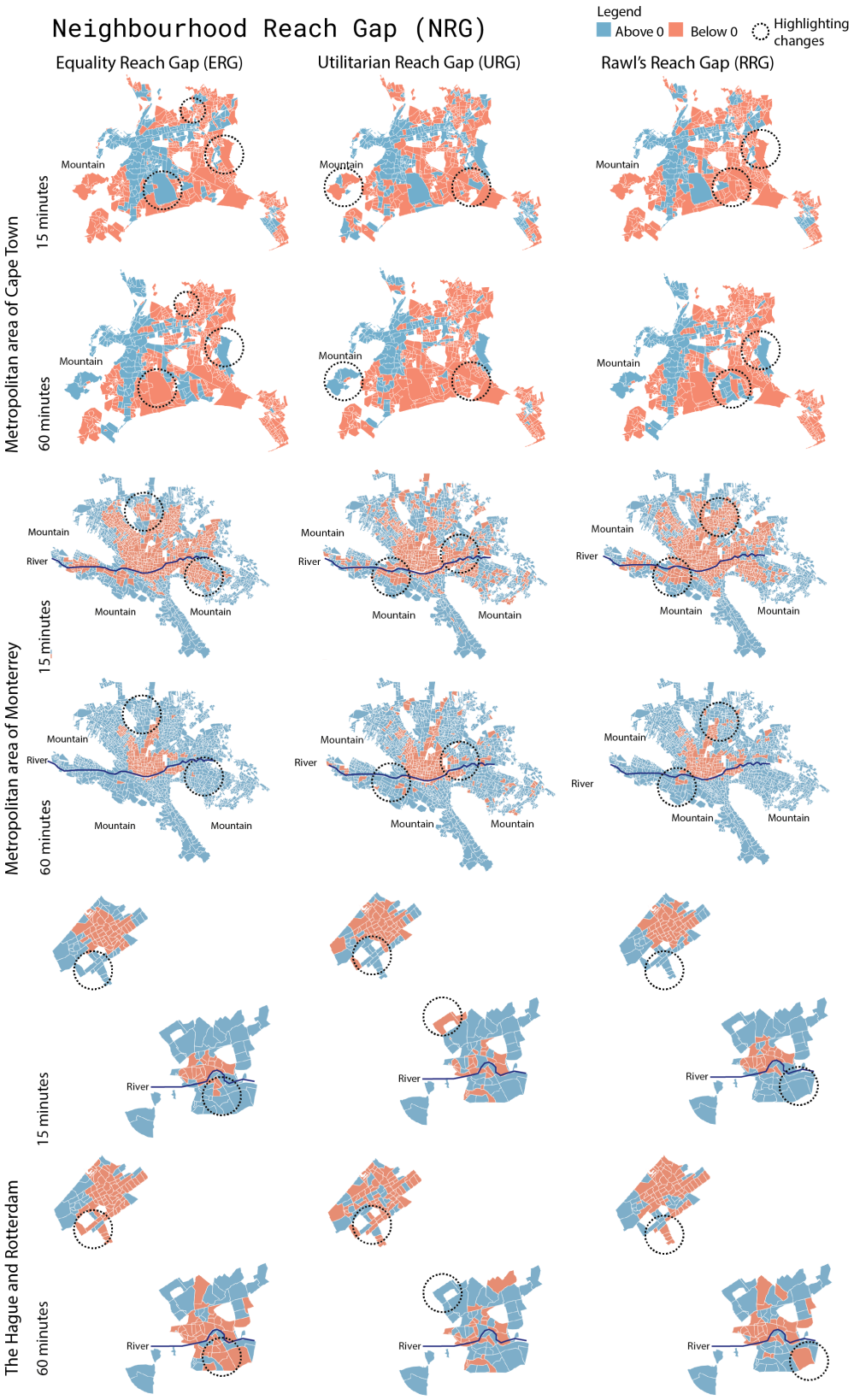

Figure 2.5: This figure displays maps of every neighbourhood for each case and whether they meet the requirements for justice (a gap metric above or equal to 0) from a particular ethical perspective at 15 and 60 minutes. If a neighbourhood meets the requirements for justice it is displayed in blue, if it does not meet the requirements for justice and is displayed in orange. This visualisation illustrates that spatial justice for neighbourhood accessibility varies temporally.

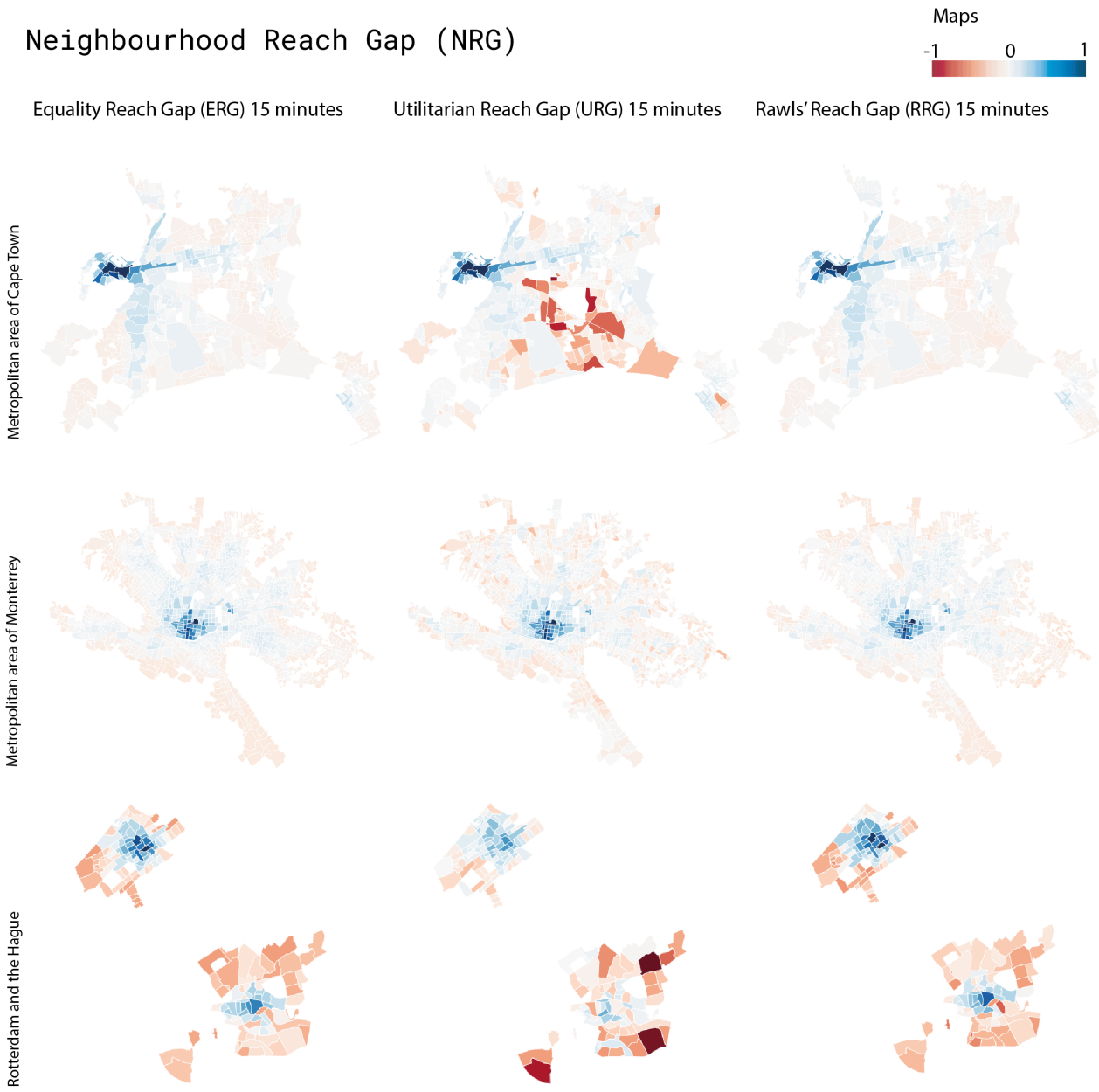

Figure 2.6: This figure visualises choropleth maps of the Neighbourhood Reach Gap (NRG) distributions according to three ethical perspectives of Equality, Utilitarianism and Rawls' Egalitarianism across the cases at 15 minutes. A gap signifies whether neighbourhoods meet the criteria for spatial justice according to a particular ethical perspective. A negative gap is highlighted in shades of red, and a positive gap is highlighted in shades of blue.

Table 4: Definitions of Theories of Justice

Theory	Definition
Utilitarianism	Justice is achieved when the welfare of a society is maximised as a whole Its main concern is the maximization of whatever social outcome is most important and for the most amount of people (Sandel, 2010).
Equality	Justice is achieved when all people receive the same benefit or treatment (Lewis et al., 2021).
Rawl's Egalitarianism	Justice is achieved when the total benefits of the most vulnerable groups in society are maximised (Fainstein, 2016).
Sufficientarianism	Justice is achieved when everyone has at least a sufficient amount of resources or opportunities to meet their basic needs or attain a certain standard of well-being. (Martens, 2017).
Prioritarianism	Justice is achieved when improvements in well-being or resources are weighted more heavily for those who are worse off meaning that it is more important to help those who are less advantaged than to provide equal gains to those who are better off (Martens, 2017).

2. Who are the stakeholders who effect future urban development in Cape Town and what is the hierarchy of stakeholders in relation to each other?

3. What are 5 strategies to overcome barriers to access in Cape Town and can you group them thinking about how likely they are to come to fruition and by the stakeholders involves.

3.3 Scenario development

Driving Forces

The ten most important driving forces which were identified through the analysis of the interviews derived from the stakeholder engagement are summarised subsequently.

1. Strength of institutional relationships

The fragmented nature of transportation governance and the complex relationships between institutional entities (both formal and informal) has a clear impact on the development, operation and regulation of transport systems in the CoCT. This was especially cited in relation to the complex relational dynamics between the minibus taxi industry and government, where there has been a long historical divide in objectives. One speaker, in discussing this, labelled the industry as the "grudge purchase" of urban planning decisions, comparing it to a service entrance to the city, symbolising the industry's historically marginalised status.

2. Levels of multi-modal integration

Levels of multi-modal integration refer to the degree of coordination across organisational, operational and physical spheres of alternative transport modes. This was cited as having clear impacts on transportation networks, timetables, transfer times and fare systems. One speaker in discussing the issue focused on how her domestic worker has to take 2 taxis and 2 buses to work, with long waiting times in between services.

3. Strength of political will

Table 5: Codes, Themes and Examples

Theme	Example of codes	Example in sentence
Strength of institutional relations	Co-ordinated governance, taxi shut down, capacity building, different goals National vs local, communication	"I know they are trying to get the spatial planning and transport departments to talk to each other."
Levels of multi-modal integration	Competition, integrated travel, integrated integrated payment, integrated transitions fares, singular payment system, network optimisation, effciency	"A success metric is if there's a seamless transition. If a customer uses a provincial bus then changes to an inner-city bus they & don't feel a difference."
Strength of political will	Vision, political pressure, leadership, implementation, alignment, stability	"Everyone knows what the right thing to do is. But there's no political vision."
Trust & Accountability	Communication, historical legacy taxi associations, trust across government, accountability	"There are barriers, there's trust issues and across the taxi associations."
Funding	Market economy, fuel price, tax rates, subsidisation investment, grants	"Our ability to be able to spend on certain bits of infrastructure is a real worry and a concern."
Railway functioning	Railway governance, funding, lack of service, vandalism, network fragmentation, frequency	"So if you can secure the railway through institutional structures that responds to the station burning, cable theft."
Prioritisation of Active Travel	Walking, cycling, prioritisation cycling lanes, behaviour, last-mile travel	"It is difficult for me to cycle in the City of Cape Town"
Safety of people and infrastructure	Security, safety of, assets, land invasions, discrimination, taxi violence, cycling	"Sometimes you're stuck. If you walk through District 6 you will get robbed."
Community agency	Society, communication, commuter's needs, affordability public engagement, knowledge	"Communities don't really have a voice in the transport systems we use."
Push for carbon neutrality	Non-motorised transport, low-carbon network, green technology, behaviour	"The future will be underpinned by having an almost zero impact on the environment."

It became clear through the interviews, if politicians lack strong political will and vision, policy frameworks do not get implemented. Municipal administration is constrained by the visions of politicians, through budget allocation and ability to implement policy.

4. Trust and Accountability

Trust and accountability between the stakeholders (such as government and minibus taxis), but also the general public is identified as key for transformation. The interviewed Ward Counsellor highlighted the need for a more professional, holistic approach to political oversight to improve accountability through a more informed public.

5. Funding

Funding on multiple levels was cited as a key uncertainty, from grants, subsidies and the strength of the wider economy. Development is constrained by funding and investment.

6. Railway functioning

The majority of participants believed the railway should be the backbone of public transport due to its speed and capacity to carry so many passengers. However, it is vulnerable to mismanagement, insufficient funding and vandalism.

7. Prioritisation of active travel

Active travel speaks to non-motorised forms of transport, such as cycling and walking. Prioritising active travel would involve travel behaviour change and community advocacy to push the government to prioritise infrastructures that support walking and cycling.

8. Safety of people and infrastructures

The degree to which a person feels unsafe will influence their travel behaviour - likelihood to walk, cycle, or even use public transport. Furthermore, safety of infrastructure against vandalism affects its ability to function efficiently and attract investment.

9. Community Agency

Community agency refers to the ability for communities to organise, take action, and effect change to address their own transportation needs through governance, policy and operation.

10. Push towards carbon neutrality

This refers to the receptiveness of society to change behaviour and government to implement policies that support carbon neutrality. This could involve supporting modes of transport that are less carbon-intensive and transforming existing fleets.

3.4 Measuring Equity of Access through MAP

Creation of Urban Network Model

A UNM can be understood as a large network consisting of vertices and edges. The vertices represent locations such as street intersections, areas of non-residential land use, or public transportation stops/stations, each with specific coordinates. The edges define the connections between these points,

Table 6: Rating each factor per scenario: 1: low; 2: low-medium, 3: medium; 4-medium-high, 5: high

Key factor	Current	Business as usual	Integration	Active travel
Strength of institutional relations	2	1	5	3
Levels of multi-modal integration	2	1	5	3
Strength of political will	2	2	5	4
Trust+Accountability	2	1	5	4
Funding	2	2	5	4
Railway functioning	3	4	1	1
Prioritisation Active Travel	2	2	3	5
Safety of people & infrastructure	2	1	4	5
Community agency	2	1	4	5
Push for carbon neutrality	2	1	3	4

representing streets, transport routes, or links between street vertices and land use or transit vertices. Each edge is assigned a weight based on the travel time either by walking or using public transportation. The graph is modelled as directed, meaning the edges have specific directions, which reflects the reality of transport routes that may vary for outbound and return trips. Additionally, each street vertex is associated with the neighbourhood it belongs to, allowing for vertices to be grouped later by neighbourhoods and connected to socio-economic data relevant to Cape Town's metropolitan area. We build the UNM using the NetworkX library in Python, and the Snkit library is employed to integrate land use and transport networks into the street network.

Parameters of Urban Network Models

The Urban Network models allow for the various parameters in the models which are used to represent the conditions of each scenario. In total we have 6 Urban Network Models, one to represent the Current Scenario, one to represent the Business as Usual Scenario. There are two representative models for the Integrated Scenario, referred to as Integration 1 and 2, 1 represents a condition where all modes are integrated and 2 where all modes are integrated and the minibus taxis and buses have priority lanes, meaning their travel time is reduced. There are two representative models for the Active Travel Scenario referred to as Active Walking and Active Cycling. The Active Walking allows for longer walking times and Active Cycling, the walking is replaced with cycling. The key parameters in each model which were adjusted are:

- The first parameter is the operationalisation of the Railway. For the Current and Business as Usual scenarios the Central railway line is taken out of the model. This is due to the Central Railway line, for a long time, not being fully operational in the CoCT. It represents the Current condition and a Business as Usual scenario, represents a continuation of this state.
- The second parameter is the total walking time allowed for each trip. The total travel time for each trip consists of two modalities: walking and public transport, and the base travel time for walking is a maximum of 15 minutes. Many studies show that people generally prefer 10 to 15 minutes of walking during one commute (Daniels and Mulley, 2013). In the Current scenario and Integrated travel scenarios we allow for a maximum walking time of 15 minutes for each trip. In the Business as Usual scenario, the walking time for each trip is reduced to 10 minutes only, representing a degradation of safety and walking infrastructure. In the Active Walking Scenario the walking time is doubled to 30 minutes, representing the behavioural changes of

Table 7: Data Set Description and their Sources

Variable	Data set	Sources	Description
Transport	MyCiti BRT data	University of Cape Town GTFS data	Vertices: stations/stops Edges: routes Weight: travel time
	Metrorail data	University of Cape Town GTFS data	Vertices: stations/stops Edges: routes Weight: travel time
	Minibus Taxis	University of Cape Town GTFS data	Vertices: stations/stops Edges: routes Weight: travel time
	Golden Arrow Buses	University of Cape Town GTFS data	Vertices: stations/stops Edges: routes Weight: travel time
Land use	Zoning data	Cape Town Open Data Portal	Vertices: land use
Streets	Road centre lines	OpenStreetMap	Vertices: street intersec. Edges: streets Weight: travel time
Socio-economic	Census 2010	Statistics South Africa	Data aggregated to neighbourhood scale

Table 8: Parameters of Urban Network models

Key factor	**Current**	**Business**	**Integration 1**	**Integration 2**	**Active Walk**	**Active Cycle**
Railway	Partial	Partial	Full	Full	Full	Full
Walking time	15	10	15	15	30	0
Transfer time	15	20	5	5	15	15
Bus & Taxi time	as is	as is	as is	20% decrease	as is	as is
Cycling	None	None	None	None	None	30

people shifting to walking. In the Active Cycling scenario, the walking time is 0 as this is replaced with cycling times.

- The third parameter is the transfer time between each transport mode. The transfer time between modes is a factor which indicates how integrated the different modalities are. In the Current Scenario the transfer time is set at 15 minutes, as a survey done indicates that this is the average transfer time between transport modes in the CoCT. In the Business as Usual scenario, the transfer time is 20 minutes, representing a decline in integration of modes as has been the trend over time. In the Integration Scenarios, the transfer time is reduced to 5 minutes, representing the integration of modes. In the Active Travel scenarios the transfer time remains at 15 minutes for all modes, except the railway, which is set to 5 minutes, as Active Travel would be supported by bulk infrastructure such as railway.
- The fourth parameter is the bus and taxi time. In the Integration 2 scenario the bus and minibus taxi travel times are decreased by 20%, representing a condition where these modes have been given priority lanes and signalling, which thus decreases their overall travel time.
- The fifth parameter is cycling time. In the Active Cycling scenario the walking time is replaced with cycling times of 30 minutes. This represents a condition where cycling between modes and for last mile travel has become the norm across the city.

3.5 Results

Stakeholder and institutional analysis

Table 9: Characteristics of Public Transport in Cape Town

Mode	Modal share*	Operated by	Payment	Subsidised
Train	2013: 18% 2023: 2%	PRASA	Bought at train stations	National subsidy
Bus	2013: 6% 2023: 7%	GABs	Golden card (reusable top-up card)	National subsidy
MyCiti BRT	2013: 2% 2023: 2%	Municipality	Myconnect card (reusable top-up card)	Municipal funded
Minibus Taxis	2013: 12% 2023: 22%	Individual owners belonging to Associations	Cash to driver	None

*Data derived from the Comprehensive Integrated Transport Plan (CITP, 2023)

4 MAP: Mapping Accessibility for Ethically Informed Urban Planning

4.1 Introduction

Disparities in accessibility make it challenging for people to break out of a cycle of poverty, leading to the reproduction of disadvantage from one generation to the next. A person's accessibility can be understood as the socio-economic opportunities they derive from their proximity to places such as employment, healthcare and educational facilities (Geurs and van Wee, 2004). Ethical principles have historically been employed by philosophers to guide thinking about reshaping society towards more fair and equitable outcomes. Many ethical theories exist which define fairness differently. Over the last ten years there has been growing concern to operationalise different theories into metrics to

evaluate equity of accessibility (i.e. Golub and Martens, 2014; Lucas et al., 2016).

However, the operationalisation of different metrics has tended to be based on the adaption of existing high-level indices from economics, such as the Gini Index and they have rarely been designed so that different metrics, based on different notions of fairness, can be compared within a single comparative framework. The advantage of placing different metrics based on different notions of fairness, justice or equity into a single comparative framework is that it allows the stakeholder, researcher or policymaker to explicitly focus on fairness from different perspectives and to visualise and compare the trade-offs between them. Equity is a contested notion, without one singular definition, representing a balance between competing ethical principles (Peyton Young, 1994). While it may not be impossible to achieve complete equity or equality in access due to the inherent limitations of urban growth, a fundamental purpose of urban policy is to guide efforts towards more equitable and just urban and transportation development (Delbosc and Currie, 2011; Litman, 2022). There is thus a need to include equity considerations within transportation appraisals, to support ethically informed decisions and enable debate amongst stakeholders.

In this paper the MAP: Mapping Accessibility for Ethically Informed Urban Planning software package is described, which was developed initially to support research conducted by Nelson et al (2025). The notebooks provided in the software package are written in Python and can be adapted to a researcher/stakeholder's own data for any context, but an example data set from Cape Town in South Africa is also made available for illustrative purposes. This package supports the creation of an urban network model (UNM) tailored towards specific urban regions. Such a tailored representative model links land use, transport and street networks into a large graph (see Figure 4.7a). Following this, it enables the calculation of Neighbourhood Reach Centrality, which is a cumulative accessibility metric that counts the number of opportunities reachable using different forms of transport within different time thresholds from each included neighbourhood (see Figure 4.7b). Finally, three metrics based on Egalitarian, Rawlsian and Utilitarian ideals are applied which allow for the evaluation of accessibility based on these principles (see Figure 4.7c). Whilst an Egalitarian approach prioritises policies which support equality, a Utilitarian perspective favours policies which maximise benefit for the greatest number of people (even at the cost of a minority) and a Rawlsian outlook supports policies that place an emphasis on the maximum benefit being derived for the most vulnerable (Fainstein and DeFilipp, 2016). These metrics are referred to as Equality Reach Gap, Rawls' Reach Gap and Utilitarian Reach Gap, as they focus on the difference between the existing and ideal access for a neighbourhood. The package could also be extended to include other conceptual notions of justice such as sufficientarianism (see Martens, 2016). The outcome of the package is a series of maps which visualise these metrics. These maps can be used as a boundary object within stakeholder engagement to integrate issues of spatial justice into the decision-making process. Boundary objects are artefacts, such as a map, image or narrative, which can be used to translate alternative viewpoints and initiate collaborations between divergent stakeholders (Star and Griesemer, 1989). Bridging different viewpoints and interests is necessary for future planning, which ultimately requires aligning different stakeholders in decision-making (Willems et al, 2022).

There are four main sections in this paper. The Data Requirements section contains an overview of the data requirements, followed by the Software Package Description which provides an explanation of the 4 different folders contained in the package. The Notebook Processes section maps the processes followed in each of the 6 example notebooks. Finally, the implications and use cases of the software package are considered within the Discussion.

4.2 Data Requirements

This software package has been designed with specific sample data for illustrative purposes. The sample data contains datasets relating to the Metropolitan area of Cape Town in South Africa and

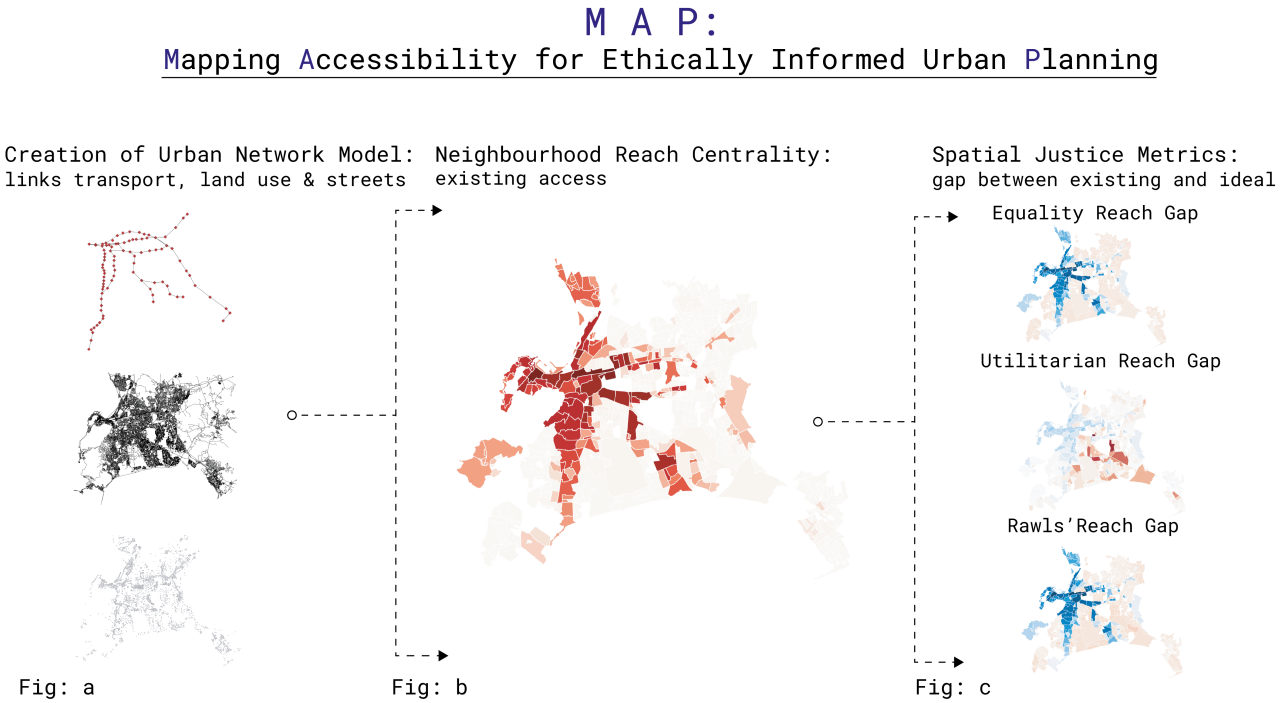

Figure 4.7: This figure presents MAP, which is comprised of three stages: 1. development of an Urban Network Model (UNM) for each case, 2. calculating Neighbourhood Reach Centrality (NRC) for every neighbourhood and 3. developing and applying metrics for Spatial Justice based on three ethical perspectives of Equality, Utilitariansm and Rawls' Egalitarianism for comparative purposes.

can be accessed here. There are four data sets required, as described below. The exact structure of each data set can be found in the *Metadata folder*.

Point of Interest Data

The land use data must be in point geometry format (i.e. shapefile/GeoJSON) and contain the points of interest that one is interested in calculating accessibility to. In the example data, places of employment are provided with the name of each type of place of employment and associated co-ordinates. Other examples of relevant points of interest are parks, healthcare and educational facilities.

Transport data

For each transport mode, two separate files are required. The first file should be in shapefile/GeoJSON format and represent the routes of the transport network with columns for the names of the source station/stop, target station/stop, associated travel time for that route in minutes and line geometry. The second file should be in comma-separated values (csv) format, representing the stations or stops of the transport network. It would have columns for their associated names and x and y coordinates. For both files, it is important to ensure that the names of the stations/stops are unique and not duplicated. This can be verified in Python using the unique method and if they are not unique, a unique code should be assigned to each one. The example data sets contain data for both the MyCiti Bus Rapid Transit (BRT) and MetroRail train transportation networks in Cape Town.

MAP is specifically designed not to require General Transit Feed Specification (GTFS) data, as many countries do not have readily available transport data in this format. This allows for the utilisation of data in alternative formats, derived, for example, from official government sources, transport agencies, Google Routes API and OpenStreetMap. Google Routes API is a particularly useful resource for transport data, especially in relation to extracting travel times between stations/stops. If the user is in possession of GTFS data, for a specific transport mode, it can be simplified to the formats described in

the previous paragraph by extracting the station/stop names, coordinates and average travel times. If a user aimed to model changing accessibility levels throughout the day based on GTFS data, multiple urban network models could be created using MAP from extracted travel times at different points in the day.

Socio-economic data
The socio-economic data is linked to the neighbourhood administrative unit within a shapefile/GeoJSON file. The example data has columns for the name of each neighbourhood, total population, total population above 18, total population with a matric diploma (finished Grade 12), total employed population, population between the ages of 18 and 65, average income in Rands and polygon geometry.

4.3 Software Package Description

The following section describes the four folders contained within the software package: the Metadata folder, Libraries folder, the Py folder and Notebooks folder, for which an overview is given in Figure 4.8.

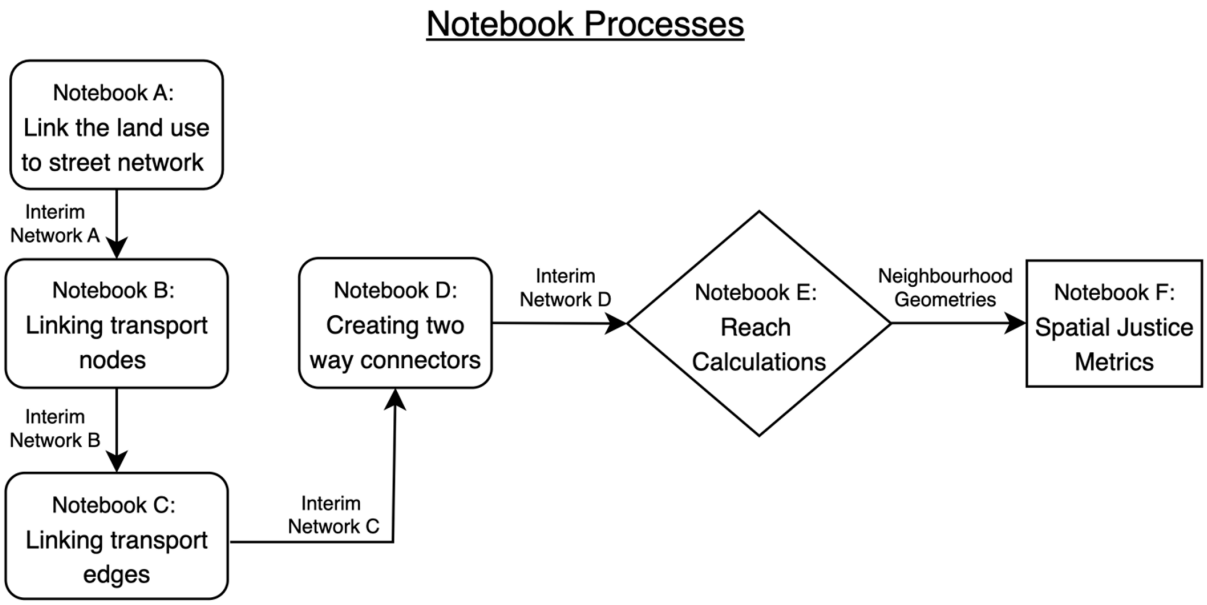

Figure 4.8: A figure summarising the processes and order of the notebooks shared in the Repository.

Metadata folder The Metadata folder contains two excel files. The first excel file is called Data Dictionaries and possesses data dictionaries which describe the contents, format, and structure of each example dataset as well as the final vertices and edges created in the notebooks. Each data dictionary explains what each of the variables refers to in as well as the format of each variable, i.e. string, float etc. The second excel file is called Notebook descriptions and contains a list of all example notebooks with a basic summary of their purpose.

Py folder
This folder contains the spatial_justice.py file which possesses the Reach and Spatial Justice functions. This file is imported into the notebooks to calculate Neighbourhood Reach Centrality, Equality Reach Gap, Utilitarian Reach Gap and Rawls' Reach Gap.

Libraries folder
This folder contains a markdown file with the list of Python packages which need to be installed prior

to running the notebooks.

Notebooks folder
This folder contains the Jupyter Notebooks containing Python code, for which there are three subfolders.

Graph Preparation: This folder contains four example Jupyter Notebooks which have code for preparing the Urban Network Model. The Urban Network Model is essentially a large graph composed of a set of vertices and edges. The vertices possess coordinates representing the positions of street intersections, non-residential land use or transportation stops/stations. The edges, alternatively, represent the connections between the vertices, which are streets, transportation routes, or a connection signifying an interchange between a street vertex and a land use or transportation vertex. Each edge is weighted by the time t it takes to traverse it by walking or public transport. Furthermore, we adopt a directed graph representation, meaning that all edges in the graph G have directionality.

Reach Calculations: This is a folder which contains a Jupyter Notebook for calculating Neighbourhood Reach Centrality. Neighbourhood Reach Centrality is a cumulative accessibility metric which represents the number of opportunities, in this case, places of employment, that can be reached within a given time threshold T.

Spatial Justice Calculations: This contains the Jupyter notebook which calculates the Spatial Justice Metrics, which represent what the gap is between the existing and ideal Neighbourhood Reach Centrality for each neighbourhood based on interpretations of Egalitarian, Utilitarian and Rawlsian ethical principles.

4.4 Notebook processes

Whilst each notebook contains clear sections and comments describing what each line of code does, a broad overview of the processes followed in each notebook are summarised below, with an overview given in Figure 4.9.

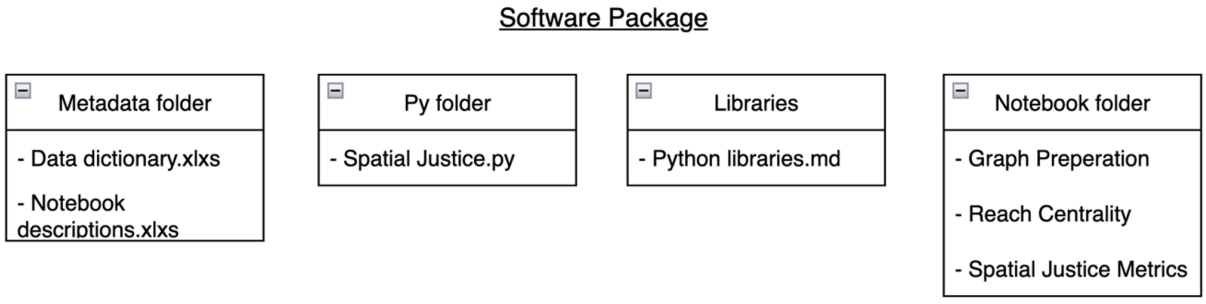

Figure 4.9: An overview of the folders contained in the software package and their files/subfolders.

Network A: Linking the road network and land use data
The purpose of Notebook A is to connect the land use data to street network data. The street network is downloaded from Open Street Map (OSM) in the form of a graph using the OSMnx library. The street network is converted into two GeoPanda DataFrames containing the edges and vertices. The land use data is loaded into the notebook as a GeoPanda DataFrame. The street vertices and land use vertices are concatenated into one DataFrame. Using the library SNKIT, each land use vertex is connected to the nearest street edge through the creation of a new connecting edge (labelled

land use connectors) between the land use vertex and a newly created vertex on an existing street edge. Following this, both the edges and nodes are reduced to specific columns and given certain characteristics, to, for example, label each land use or street edge/vertex as such. The network is exported as edges and vertices in two separate shapefiles, which collectively are referred to as Network A.

Notebook B: Linking the transport network/s
The overarching point of Notebook B is to link the transport vertices to Network A. The edges and vertices of Network A and the MyCiti BRT vertices are loaded into the notebook as DataFrames. Prior to connecting the BRT vertices to Network A, the land-use connectors need to be separated from the streets so that the BRT vertices only connect to the nearest streets. The SNKIT library is used to link the BRT vertices to the street network through the creation of a connecting edge between each BRT vertex and a newly created vertex on an existing street edge. The previously separated edges and vertices are then rejoined with this network. The network is exported as edges and vertices in two separate shapefiles, which collectively are referred to as Network B. This notebook would be run for each transport network one needs to connect. In the case of the example data, it would be run twice to connect the BRT and Railway vertices.

Notebook C: Concatenating the transport routes
The main purpose of Notebook C is to add the transportation routes to the edges from Notebook B. Prior to importing the Network B edges, the lengths of each edge are calculated in QGIS using the Field Calculator in the Attribute table. QGIS is an open-source Geographical Information Systems software. Although the lengths could be calculated in Python, it is more accurate in QGIS as it considers the curvature of the earth. The length of each edge is stored in a column called Length. The Network B edges and transport routes are loaded in as DataFrames and then concatenated together. A new column is added to the edge DataFrame called time-cost, and populated with the time it takes to traverse each edge through average walking time. Specific times are given to each connector edge, depending on whether it connects land use or transport to the street network.

Notebook D: Creating two-way connector edges
The purpose of Notebook D is to create two-way edges for the connecting edges which were created in previous notebooks. The connecting edges are one-directional. They need to be two-directional as the final graph will be a directed graph representation, meaning that each edge has direction.

Notebook E: Calculating Neighbourhood Reach Centrality
The purpose of Notebook E is to calculate the Neighbourhood Reach Centrality (NRC) for every single neighbourhood. The edges created in Notebook D, the vertices from Notebook C and the neighbourhood geometries are imported as separate DataFrames. The Spatial Justice.py file is also imported.

The imported vertices are spatially joined with the neighbourhood geometries, to provide each vertex with the name of the neighbourhood in which it is positioned. The vertices and edges are transformed into a NetworkX graph. The target vertices are defined, which in the example are the employment vertices. The source vertices are defined as all vertices which are street vertices. The source vertices are grouped by neighbourhood, so that the NRC calculation is done from each neighbourhood, instead of each individual vertex, to enable the results to be linked to the socio-economic data.

The NRC values are calculated using the calculate_reach_centrality function imported from the py file. This function allows the counting of places of employment that can be reached within different overall time thresholds and a maximum walking time threshold. The NRC is calculated at 15, 30, 45 and 60 minutes for each neighbourhood. A new DataFrame is created with the reach values, socio-economic variable and geometries. The neighbourhood geometries are exported and saved.

Notebook F: Spatial Justice Metrics
The purpose of Notebook F is to calculate Equality, Utilitarian and Rawls' Reach Gap. Each of these metrics operationalise three alternative ethical principles to evaluate accessibility at the neighbourhood scale (Nelson et al, 2025). The notebook encompasses a number of computational steps, which are summarised below:

- The neighbourhood geometries shapefile created in Notebook E and the spatial_ justice.py file are imported.
- The socio-economic data is normalised between neighbourhoods to allow for relative comparisons between them.
- The equality, utility and rawls functions are imported from the spatial_justice.py file. These functions allow for the calculation of ideal access and the gap between the ideal and existing levels of access based on Egalitarian, Utilitarian and Rawlsian principles. In all three frameworks, a gap value of zero or greater indicates that a neighbourhood meets or exceeds the respective justice criterion. From an equality perspective, the ideal access for each neighbourhood is grounded in the principle of equality, which posits that all neighbourhoods should ideally have the same level of access to available opportunities (Nelson et al., 2025). Based on this framework, NRC is adjusted, by the equality function, so that each area is allocated an ideal level of accessibility equal to the average access. From a utilitarian perspective, access should be maximised for the neighbourhoods with the greatest populations (Nelson et al., 2025). Based on this, NRC is adjusted, by the utility function, to be proportional to the size of each neighbourhood's population. From a Rawlsian perspective, accessibility should be maximised for those who are most vulnerable (Fainstein, 2016:263). Practically, this view holds that accessibility should be distributed in line with a neighbourhood's degree of vulnerability (Nelson et al., 2025). Access is reallocated proportionally, by the rawls function, to each area's vulnerability score. This score is a composite index and is a value between 0 and 1 based on the vul_score function which determines the average vulnerability level for each neighbourhood based on the included socio-economic indicators such as income, employment, and education levels.
- The final step involves visualising the results in maps for comparison.

4.5 Discussion

The MAP software package presented in this paper aids in the operationalisation of metrics of spatial justice for comparative purposes to evaluate accessibility based on different notions of justice. The final outcome of the software package is a series of maps which visualise the evaluation of accessibility from different ethical perspectives at the neighbourhood scale, as shown in Figure 4.7c. Whilst there are many software packages which allow for the calculation of accessibility, they are often based on GTFS data, of which many countries and transport agencies do not make readily available. There are limitations associated with open-access data, such as potential incompleteness or inaccuracies. However, when working in regions which are data scarce, they are a vital source of information.

This software package has the potential to enable justice considerations to be brought into processes of deliberation amongst different stakeholders within urban planning processes and facilitate new research projects, especially in regions with scarce data. The maps and insights generated by MAP can be utilised as a boundary object - a common reference point - to aid in the facilitation of integrating justice considerations into processes of stakeholder engagement and management. For future research, MAP can be adjusted to include additional metrics of spatial justice based on alternative ethical perspectives. It can also be utilised for educational purposes, to train the next generation of engineers and urban planners to incorporate equity into urban and transportation appraisals as a key consideration towards achieving the United Nations Sustainable Development Goals, particularly Goals 10 and 11.

Curriculum Vitae

Ruth Joan Nelson was born in South Africa, which is considered to be one of the most unequal countries in the world. From a young age, she witnessed the devastating effects of inequalities on people's lives. This led to an understanding of the impact of *place* on a person's ability to socially uplift themselves through access to transport, employment, educational, health and social opportunities. Having lived and worked in five countries, Ruth came to realise that whilst these issues may be extreme in South Africa, they are not isolated to it, which has driven her commitment to advance knowledge on urban inequalities.

Ruth has both a Master's in Architecture (Nelson Mandela University) and MRes. in Space Syntax (University College London). Her practice and research are embedded in systems thinking approaches and evidence-based methods that draw on data science, digital technologies, AI, complex network science, urbanism, architecture and sociology. Her skills lie in linking data analysis and computational methods with decision-making for urban planning, design and policy. As her work is relevant beyond academia, she frequently collaborates with organisations such as TU Delft Global (Netherlands), Urban AI (France), the Local Government Information Unit (UK) and Young Urbanists (South Africa). Her aim is to support the development of more equitable policies and design solutions through participatory processes by harnessing the power of digital technologies and spatial data science.

Academic Publications

1. Nelson, RJ., Warnier, M. and Verma, T. (2025). MAP: Mapping Accessibility for Ethically Informed Urban Planning. (under review) (Part of this dissertation)

2. Nelson, RJ., Warnier, M. and Verma, T. (2025). Ethically informed Urban Planning: measuring distributive spatial justice for neighbourhood accessibility. (under review) **Awarded Best Paper in Spatial Analysis at the GISRUK Conference in Leeds 2024** (Part of this dissertation)

3. Nelson, RJ., Pearce, B; Warnier, M. and Verma, T. (2025). Constructing Just Mobility Futures. (Under review) (Part of this dissertation)

4. Nelson, R., Warnier, M., Verma, T. (2024) Housing inequalities: The space-time geography of housing policies. Cities 145, 104727. (Part of this dissertation)

5. Nelson, R., Warnier, M., Verma, T. (2024) Conceptualizing Urban Inequalities as a Complex Socio-Technical Phenomenon. Geographical Analysis 56, 187–216. (Part of this dissertation)

6. Nelson, RJ. (2022). Social inclusion through the urban lens: a comparative analysis of neighbourhoods of residential racial homogeneity and heterogeneity in Cape Town, South Africa. 13th Space Syntax Symposium. Norway [link]

7. Nelson, RJ. (2021).The spatial and social logic of the Minibus Taxi network: how access may support social inclusion in Cape Town, South Africa. Applied Mobilities 8, 1–27.

8. Nelson, R.J. (2019). An analysis of the urban morphological development of Cape Town, South Africa with a specific focus on emergent spatial and mobility systems that generate the opportunity for multi-racial co-presence. Masters Dissertation [link]

Policy Briefs

1. Nelson, R.J., (2021). Zoning access: a reflection on the relationship between accessibility and land use management in South Africa. LGIU . [link]

2. Nelson, R.J. (2021). Is a Smart City a Good City?. LGIU [link]

3. Nelson, R.J. (2025). Planning for Justice. (forthcoming)

Reports

1. Nelson, RJ., Min Naing, K. and Beroche, H. (2023). Generative AI for Urban Governance. Urban AI

Invited Webinars

1. Urban AI for Sustainability, 2024.
Hosted By: Urban AI and Cornell Tech

2. Housing Inequalities, 2024.
Hosted By: Space Syntax Laboratory, University College London, UK

3. Insights into Emerging Technologies and Urban Inequalities, 2023.
Hosted By: UNESCO Chair in Urban Landscape

4. Urban social inequalities: How can cities include people? 2023.
Hosted By: IE University and All things Urban

5. Getting Density Right, 2022.
Hosted By: Young Urbanists in partnership with the Mayor of Cape Town

6. Social inclusion through the urban lens, 2022.
Hosted By: South African Centre for Cities

Invited Guest Lectures

1. The Healthy and Inclusive City Minor - TU Delft
Lecture Title: An African urban perspective on the healthy and inclusive city

2. Health and Society Minor - TU Delft
Lecture Title: An African urban perspective on the healthy and inclusive city

3. Complex Systems Engineering Masters Course- TU Delft
Lecture Title: Shaping Urban Futures: Navigating Socio-Technical Systems for Equitable Access

4. African Dynamics Masters Course- TU Delft, Leiden University
Lecture Title: Incorporating equity into accessibility evaluations of urban transportation scenarios in Cape Town, South Africa.

Conferences

1. Urban Technology for Equity, 2024.
Hosted by: United Nations Innovation Technology Accelerator for Cities - Invited as a Speaker

2. Reinventing the City, 2024.
Hosted By: AMS Institute, Amsterdam, Netherlands

3. African Transport Research Conference, 2024.
Hosted By: University of Cape Town, Cape Town, South Africa

4. GISRUK, 2024.
Hosted By: University of Leeds, Leeds, United Kingdom

5. Benchmarking Spatial Justice in Policymaking, Planning and Design, 2023.
Hosted By: TU Delft, Delft, Netherlands

6. Annual Meeting for the American Association of Geographers, 2023.
Hosted By: American Association of Geographers, Denver, United States

7. 13th International Space Syntax Symposium, 2022
Hosted By: Western Norway University, Norway

8. GISRUK, 2022.
Hosted By: University of Liverpool, UK

9. Fifth South African Cities Conference, 2020.
Hosted By: University of the Witwaterstrand, SA

10. Ocho Semana Conferencía, 2020.
Hosted By: Universidad Auntonoma de Nuevo Leon, Mexico

11. Masters in Research Conference, 2019.
Hosted By: Bartlett School of Architecture, UK

Seventy percent of the world's population live in countries where inequalities have increased over the past three decades. There is growing recognition that global understandings of inequality must be complemented by empirically grounded, context-sensitive analyses that incorporate spatial and temporal dimensions. This dissertation advances that agenda by exploring the structural drivers of urban inequalities through a methodological approach that integrates critical theory with spatial data science. Central to this approach is the development of a theoretical framework that synthesises geospatial analysis and complexity science. This framework is operationalised through its iterative application to three empirical case studies drawn from both the Global North and South, enabling a comparative perspective on urban inequalities. By bridging critical theory with novel empirical methods, the research contributes to contemporary debates on urban inequality, offering conceptual and methodological innovations as well as policy-relevant insights.