Spatial analysis exploring the influence of stream daylighting in building resilient urban form: A study of Zürich, Switzerland's 'Bachkonzept' for stream daylighting

by

Harshitha Damodaran

A thesis

Presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Environmental Studies

in

Planning

Waterloo, Ontario, Canada, 2021

Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Cities face several risks that jeopardize their adaptability as the effects of climate change and urbanization on our ecosystems intensify. Recognizing the potentially disastrous outcomes of inaction, local governments and organizations are developing climate-adaptive strategies to preserve and restore our ecosystems sustainably. Stream daylighting, an example of Nature-based solutions (NbS), has the potential to provide long-term solutions to climate change while also providing numerous health, cultural, and recreational benefits to humans. Despite the numerous benefits of stream daylighting, limited research exists on how or if stream daylighting can boost urban form resilience.

As a first step towards filling this knowledge gap, this study takes an experimental case study approach to analyze the impacts of stream daylighting on the urban form to enhance climate resilience in the City of Zürich following the implementation of 'Bachkonzept' or 'stream concept'. As such, this study examines the urban form of three daylighted districts in Zürich using spatial statistical tools and readily available open data sources.

The emphasis is on feature-based urban form attributes that drew empirical connections between Kevin Lynch's 'fit' dimension of Good City Form and Ian McHarg's concept of 'ecological determinism' or 'fitting' to judge the district's climate performance. Urban form attributes such as compactness, population and employment density, diversity of land uses and lot sizes, and the spatial arrangement and distribution of urban open spaces are examined and analyzed.

The empirical evidence from this research supports the theory that stream daylighting, when perceived as a city-wide policy, paves the way for a highly manipulable, resilient, and adaptable urban form. The findings from this research show that the urban form in the areas surrounding daylighted sections of the stream support moderate levels of density along with an appropriate mix of land uses and a good supply of urban open space. These conclusions strengthen the notion that stream daylighting, as a Nature-based solution, holds a lot of potential in enhancing the overall urban resilience in a city, in addition to bringing nature back into dense urban neighbourhoods.

Acknowledgements

I am grateful to my supervisor Dr. Luna Khirfan for her encouragement and support throughout my graduate journey. Your thoughtful feedback pushed me to sharpen my thinking and elevate my work. My heartfelt gratitude also goes to Dr. Rob Feick for his interest in my research and his valuable contributions in redefining the spatial tools used to shape this thesis.

A huge thank you to all the fantastic people I have met during my time at the University of Waterloo. Thank you for all the memories and moments, which I sure will cherish forever. Special thanks to all my friends for always checking in on me, lifting my mood with laughter, and reminding me to be patient and kind with myself during these challenging times.

I am truly blessed for my wonderful family for supporting and loving me throughout despite living thousands of kilometres away. Thank you, mom and dad, for everything you have done, for your selflessness and for providing me with the opportunities and support needed to succeed. Thank you for always believing in me and pushing me to achieve my dreams and goals; none of this would have been possible without you two!

Lastly, to my partner Para, you have been supporting and cheering me on since day one. Thank you for all the little things you have done every day, for putting up with my frustrations, and always reciprocating them with compassion. Thank you for constantly pushing my limits and lifting my spirits even when I could not- I am truly fortunate to have you.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

1.1 Background

Urbanization, a megatrend of the 21st century, is a global phenomenon that is rapidly transforming our cities (Seto et al., 2014). Cities and urban areas are complex human-natural systems, and when humans alter natural landscapes, the dynamics of ecosystems change. This endangers our ecosystems by causing habitat fragmentation, isolation and degradation, homogenized species composition, and disrupted hydrological flows and nutrient cycles, to name a few (Alberti & Marzluff, 2004).

Urbanization affects ecosystems and their associated services by increasing impervious surface areas, affecting both geomorphological and hydrological processes (Leopold 1968, Arnold and Gibbons 1996; Alberti, 2008). Ecosystem services are the various benefits that humans receive from the environment like provisioning services (e.g., food, water, and materials), regulating services (e.g., climate regulation, disease regulation, water purification), supporting services (e.g., soil formation, nutrient cycling), and cultural services (e.g., recreation, education, and social relations) (Reid et al., 2005). Globally, 60% of ecosystem services are being degraded or used unsustainably, resulting in a substantial and irreversible loss of biodiversity (MEA, 2005).

Resilience, a polysemic concept, is frequently used as an organizing guideline to assist planners and decision-makers in determining how cities can thrive in the face of shocks and external pressures. Moreover, one of the avenues through which planners make mediations into the urban system is through physical city form (Sharifi, 2019). Urban resilience is defined as “the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales- to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (Meerow et al., 2016, p.39). Designing urban form patterns to achieve resilient cities is now increasingly recognized (Creutzig et al., 2016; Gleeson, 2012; Sharifi, 2019). This increasing awareness to build resilience emphasizes the need to improve urban form and growth patterns to better respond to climatic challenges, providing a significant opportunity for urban areas to build their adaptive capacities. Assessing and monitoring these urban form patterns to achieve sustainable urban growth is recognized as one of the most important challenges for researchers, planners, and decision-makers (Yildiz & Doker, 2016). It is a complex process given the multitude of variables involved in analyzing resilient urban forms in rapidly urbanizing cities.

Rapid urbanization coupled with the implications of climate change brought the concept of resilience through the lens of urban morphology to the forefront in urban planning and design (Pickett, Cadenasso, & Brian, 2013; Feliciotti, Romice, & Porta, 2018). Urban morphology is the study of urban form and the corresponding processes of formation and transformation (Kropf, 2017). Oliviera (2016, p.2) defines *urban morphology* as "the study of urban forms, and of the agents and processes responsible for their transformation, and that urban form refers to the main physical elements that structure and shape the city". Urban morphology ties the physical form of a place to other attributes of a place like land use, pedestrian activity, and social hierarchies. Urban morphology is recognized as an effective strategy to analyze the city's physical form relative to its natural and cultural context (Muratori, 1959; Whitehand, 1981; Vernez Moudon, 1994; Pattacini, 2012).

There are several ways to achieve resilient urban form (see Dhar and Khirfan, 2017). One such method is ‘harmony with nature’, meaning the coherence of nature and urban forms to enhance resilience. Objectively, ‘harmony with nature’ can be operationalized using Nature-based solutions (NbS). NbS has emerged as a concept for integrating ecosystem-based approaches to address a range of societal challenges, directly contributing to increased urban resilience (Bush and Doyon, 2019). NbS is defined as “actions which are inspired by, supported by or copied from nature” (European Commission, 2015, p.4). Notably, NbS emerged as an umbrella term for concepts like ecosystem-based adaptation, green infrastructure, and ecosystem services (Pauleit et al., 2017). In recent years, NbS is increasingly recognized as a strategy to build adaptive capacity and urban resilience while supporting biodiversity (Kabisch et al., 2016).

One such example of NbS is ‘stream daylighting’ or ‘deculverting’ (Wild, Dempsey and Broadhead, 2019). Stream daylighting is “the practice of removing streams from buried conditions and exposing them to the Earth’s surface in order to directly or indirectly enhance the ecological, economic, and/or socio-cultural wellbeing of a region and its inhabitants” (Khirfan, Peck, & Mohtat, 2020b, p.1). Improved provisioning of ecosystem services, better social amenities, and other environmental, economic, and social factors serve as critical drivers to stream daylighting. In addition to increased economic benefits through revitalized neighbourhood design and increased property value, daylighting also offers a number of ecosystem services, such as provisioning services (e.g., fresh water, food, habitat improvement), regulating services (e.g., flood mitigation, reduced run-off velocity, enhanced sewage treatment), cultural services (e.g., recreational opportunities, education and play opportunities for children), and supporting services (e.g., primary production and nutrient cycling) (Pinkham, 2000; Wild, Bernet, Westling, & Lerner, 2011). In addition to supporting and managing water systems, daylighting also holds a valuable potential in adapting to climate change by coping with excess rainwater runoff and reducing the urban heat island effect (Khirfan, Mohtat, & Peck, 2020b).

Khirfan et al. (2020b) carried out an extensive content analysis of the literature on stream daylighting and identified that empirical research rarely connected stream daylighting, built form and urban design. Moreover, the practice of daylighting is an intervention that affects land uses, and hence there is an urgent need to build empirical connections between daylighting and urban form (ibid). Accordingly, this urgency and the need to tackle daylighting as an NbS, and Khirfan et al.'s (2020b) call for the need for research that makes connections between stream daylighting and urban from is the foundation on which this research is built.

In this research, I draw upon the performance dimensions of urban form as identified by Kevin Lynch (1981) in his 'A Theory of Good City Form' to assess whether (or not) stream daylighting enhanced the resilience of urban form in Zürich. This research takes a case study approach of the 'Bachkonzept' or 'stream concept' devised by the City of Zürich to explore empirical connections between the resilience of urban form and stream daylighting using Geographical Information System (GIS) and spatial statistical analysis.

1.2 Research objectives and questions

Considering the urgent need for the analysis of urban form with respect to stream daylighting, the main objectives of this research are to explore the relationship between urban form and stream daylighting in improving the city's overall climate resilience. This research provides a quantitative methodology for assessing the climate performance of urban form surrounding stream daylighted areas in the city of Zürich, Switzerland, the districts 3, 9 and 11, which are identified as the districts that have more than 1000m of stream daylighted within the district's urban fabric. Following this, the key question this study aims to answer is:

> *How do the characteristics of urban form differ between daylighted and culverted sections of the stream? Can daylighting be used as a stimulus to enhance the urban resilience of the built environment in daylighted cities?*

The overarching hypothesis for this research is that daylighting, when implemented in a systematic method (i.e., by city-wide policy measures), paves the way for a highly resilient environment to cope with climatic uncertainties. Urban form indicators such as density, diversity, and the spatial arrangement and distribution of urban open spaces are used to assess the spatial changes, and judge the climate performance. The indicators are selected based on empirical studies that drew connections between these feature-based urban form attributes that enhance the resilience of urban form. Besides, these indicators are transferable across cities and contexts.

This methodology forms the core of this thesis and can be used for similar studies to evaluate the climate performance of the urban form. Specifically, by empirically testing the indicators of the built form and urban open space, this study aims to apply these indicators to the case of stream daylighting in the city of Zürich to explore the relationship between urban form and stream daylighting in enhancing the city's overall urban resilience and how these can inform planning policy and design considerations for stream daylighting.

1.3 Thesis structure

This thesis is organized into five chapters that are structured around key stages such as introduction (Chapter 1), literature review (Chapter 2), methods (Chapter 3), data analysis and results (Chapter 4), and conclusion and future directions (Chapter 5). The first chapter provides a research summary, including the broad research context, the research aim, objectives, and significance as well as an outline of the thesis structure. Chapter 2 examines the theories of physical city form and urban resilience in relation to NbS, and the claims and evidence that support them. It draws empirical connections with the theories to judge the urban form's climate performance. Chapter 3 presents the research methodology and the overall approach to the research. It details the background and study area of the chosen case study and the range of analyses undertaken to investigate the relationship between the variables and indicators. Chapter 4 presents the analysis of the indicators and presents the findings of this research. Chapter 5 summarizes the research's overall findings with reference to research aims and objectives.

Chapter 2: Reviewing the Literature

This chapter addresses the three broad categories of this research, namely, resilience, nature-based solutions, and resilient urban form. The literature review aims to draw parallels between theoretical and empirical framing, and in turn, arrive at specific indicators and variables necessary for assessing urban form to enhance resilience.

2.1 Urban Resilience discourse

Resilience, a concept with multiple meanings, has recently exploded in academic and policy discourse (Brown, 2013; Cascio, 2009; Meerow & Newell, 2015; Meerow et al., 2016). *Urban resilience* is "the ability of an urban system- and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales- to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (Meerow et al., 2016, p.39). This definition of urban resilience offers three dynamic pathways to urban resilience, namely, persistence, transformation, and transition/ adaptation, while advocating general adaptability and recognizing the importance of temporal and spatial scales.

Resilient systems also hold the potential "to create opportunities for doing new things, for innovation, and for development" while also responding to climatic uncertainties (Folke, 2006, p. 253; Dhar & Khirfan, 2017). Davoudi et al (2013) agree with Swanstorm's (2008, p.2) statement that resilience is a conceptual framework that intrigues us to think about climate change adaptation in a more dynamic and holistic way.

As a result of climate change, people, societies, economic sectors, and ecosystems are all at risk. IPCC (2014, p.36) defines *risk* as “the potential for consequences when something of value is at stake, and the outcome is uncertain, recognizing the diversity of values”. *Hazards* (i.e., extreme events triggered by climate change, such as severe storms, droughts, and sea-level rise), *vulnerability* (i.e., susceptibility to change), and *exposure* of people, assets or ecosystems to those hazards are the major factors that contribute to increased risk from climate change. While hazards can range from brief events to long-term trends, vulnerability and exposure are affected by socio-economic processes that increase or decrease risks depending on the development pathway (ibid). Thus, resilience is achieved by reducing these negative impacts of climate risk from the combination of hazards, vulnerability, and exposure.

Planning scholars have mainly borrowed the concept of resilience from the field of ecology (Sharifi & Yamagata, 2018). The concept of resilience is increasingly used as an organizing principle to frame scientific and political discourses on cities (ibid). Above all, perhaps, the concept of resilience can be used to enhance the coping capacity of both existing and future developments, thereby assisting in their continued functioning. In planning literature, the emergence of resilience in relation to climate change adaptation emerged about two decades ago (Sharifi & Yamagata, 2018) and is deemed by many as a bridge between urban planning and climate adaptation (Davoudi et al., 2012; Dhar & Khirfan, 2017).

As identified by Dhar & Khirfan (2017), one of the types of resilience is *evolutionary resilience*, which is the ability of a system to '*transform-forward*' while maintaining the ability to change. Evolutionary resilience broadens the scope to incorporate dynamic interplay between persistence, adaptability, and transformability across multiple scales and time frames in ecological systems (Davoudi et al., 2013; Davoudi, 2012).

From a resilience perspective, cities are "complex, adaptive socio-ecological systems, consisting of internal structures and processes, which can be understood by their self-organization, emergent properties, non linear and unpredictable dynamics and patterns of abrupt change" (Costanza et al., 1993; from Davoudi, 2013, p.312). The city's physical form is the primary medium through which planners and urban designers intervene in the urban system (Marcus and Colding, 2011; Feliciotti et al., 2017).

The built environment, one of the major constituents that make up physical city form can positively contribute to sustainable development goals (Lucon et al., 2014). Meanwhile, it can also lock in negative or undesired trajectories due to their large life spans. It is acknowledged that urban form might as well be "the most tangible dimension of cities" nested within a framework of policies and regulations, with interactions among various actors and agents, as well as different values and cultures (Marcus and Colding, 2011). In order to avoid adverse lock-in effects, it is critical to incorporate resilience thinking into urban form theories and methods (Feliciotti et al., 2017; Sharifi, 2019). Section 2.5 further details the importance of building the resilience of urban form to adapt to climate uncertainties.

2.2 Nature-based solutions (NbS) – context and association to urban resilience

The European Commission (EC) understands Nature-based solutions (NbS) as "actions which are inspired by, supported by or copied from nature", potentially "resilient to change" (EC, 2015, p.4). The EC (2015) identifies four primary goals that NbS can help address, and they are enhancing sustainable urbanization, restoring degraded ecosystems, developing climate change adaptation and mitigation, and improving risk management and resilience. It is also argued that NbS, among others, are also critical for urban regeneration, ecosystem restoration, and enhancing urban sustainability (ibid).

Notable, NbS is considered an umbrella term to other concepts such as ecosystem-based adaptation (EbA), urban green infrastructure (UGI), and ecosystem services (ES) (Pauleit et al., 2017). EbA is explicitly concerned with climate change adaptation through the use of nature, whereas UGI provides deliberate guidance for integrating NbS into urban landscapes by creating a multifunctional network of green spaces. Finally, ES refers to the benefits humans derive from urban nature. One of the primary outcomes of NbS is the delivery of ecosystem services in urban areas. These ecosystem services provided by NbS contributes to enhanced urban resilience by reducing the impacts of climate change in cities by acting as a buffer while also providing a wide range of functions benefiting humans and the cities they live in (Bush and Doyon, 2019; Kabisch et al., 2016). The concept of stream daylighting as an NbS is one of several that promote the preservation, enhancement, and restoration of biodiversity and ecosystems while addressing multiple concerns simultaneously (Kabisch et al., 2015).

Integrating NbS in urban landscapes offers multiple benefits related to climate change adaptation and mitigation (Barton and Grant 2006; Hartig et al., 2014). Some examples of NbS for climate adaptation include the provision of urban green spaces that support natural habitats to ameliorate the Urban Heat Island effect and provide buffer spaces to regulate air and water flows (Gill et al., 2007; Bowler et al., 2010). In addition, NbS also have various climate mitigation benefits such as ecosystem regulation by decreasing air pollution, reducing atmospheric temperature and CO_2 emissions (Kabisch et al., 2016). While NbS directly addresses and contributes to increased urban resilience, the potential to mainstream NbS through incorporation into urban planning approaches is still being developed in research and practice (Bush and Doyon, 2019).

UGI and NbS have shown to reduce local flooding, economic loss, and discomfort due to major storm events, but it is important to note that small-scale implementation of NbS has minimum impact on large-scale catastrophic rain events such as river flooding or intense cloud bursts (Emilsson and Sang, 2017). While there is literature that focuses on networks of NbS and Green-Blue infrastructure (see Dushkova, 2020; Artmann, 2018), there is a need to incorporate multiple spatial scales to adapt to such extreme events for NbS to be an effective climate adaptation strategy. To this end, it is evident that NbS can provide highly sustainable solutions to various societal challenges and is deeply rooted in climate adaptation.

2.3 Resilient urban form

In the planning literature, the emergence of resilience in relation to climate change adaptation surfaced about two decades ago (Sharifi & Yamagata, 2018) and is deemed by many as a bridge between urban planning and climate change adaptation (Davoudi et al., 2012; Dhar & Khirfan, 2017). The physical form of the city is the main medium through which planners and urban designers make interventions to the urban system (Marcus and Colding, 2011; Feliciotti et al., 2017). Accordingly, Oliviera (2016, p.2) defines *urban morphology* as “the study of urban forms, and of the agents and processes responsible for their transformation, and that urban form refers to the main physical elements that structure and shape the city”. Consistent with the definitions of ‘resilience’ and ‘urban form’, ‘resilient urban form’ is the degree to which it can maintain functions of urban systems in the face of a disturbance, adapt to change, and transform urban systems to enhance the adaptive capacity. A resilient urban form, thus, enables the urban system to be transitional, transformational, and adaptable while also maintaining its integrity and functionality under constantly changing socio-economic and environmental conditions (Sharifi and Yamagata, 2018).

The built environment, one of the major constituents of physical city form, can offer readily available opportunities to build the city’s adaptive capacities whilst positively contributing to sustainable development goals (Lucon et al., 2014). Meanwhile, it can also lock in negative or undesired trajectories due to their long-life spans. It is acknowledged that urban form might as well be “the most tangible dimension of cities” nested within a framework of policies and regulations, interactions among various actors and agents, as well as different values and cultures (Marcus and Colding, 2011).

2.4 Theoretical framing- ‘fit’ and ‘fitting’

The urban form has the potential to manipulate the environmental, social, and economic dimensions of urban growth and development without affecting the autonomy of the cities (Bourdic, Salat, & Nowacki, 2012). This is especially critical considering the awareness of our ever-changing world coupled with the implications of climate change bringing the concept of resilience through the lens of urban morphology to the forefront in urban planning and design (Pickett et al., 2013; Feliciotti et al., 2018).

This section of the literature review addresses the links of the three main concepts, namely, resilience, NbS, and climate change, to ‘fit’ (Lynch, 1981) and ‘fitting’ (McHarg, 1969). A theory of Good city form (Lynch, 1981) is a set of universal “rules” or normative theories that effectively strengthen the interrelationship between human activities, functions, and the city form. In contrast, Design with Nature (McHarg, 1969) aims to recognize the importance of ecology in landscapes by exploring spatial relationships between the built environment and the natural environment. Since the primary focus of this research is on the influence of daylighted streams on the built environment, the two theories (Lynch (1981) and McHarg (1969)), elaborated in the following section, inform the theoretical framework of this study.

2.4.1 ‘Fit’- A theory of Good City Form

Lynch’s (1981) A Theory of Good City Form aims to establish a comprehensive ‘normative theory’ that stems from the connections between human values and the physical city through five performance dimensions (see Figure 2.1). While each performance dimension can roughly be associated with climate adaptation, Lynch defines "adaptability" as one of the measures of the 'fit' dimension which is very similar to climate adaptability. In a real sense, 'fit' is dominated by the type of place and the breadth and amount of activities preferred and carried out (Lynch, 1981). Lynch defines 'Fit' as the degree to which city form matches the behavioural patterns of its inhabitants, which can be enhanced by modification of the former or the latter. Human behaviour is varied, and adaptable spaces that are substantially designed to match basic human patterns render a good 'fit'. In this sense, 'fit' resembles adaptability, whether through the adaptation of urban form to the changing climate or by acting as a mediator in adapting human behaviours to climate change (Khirfan, 2020).

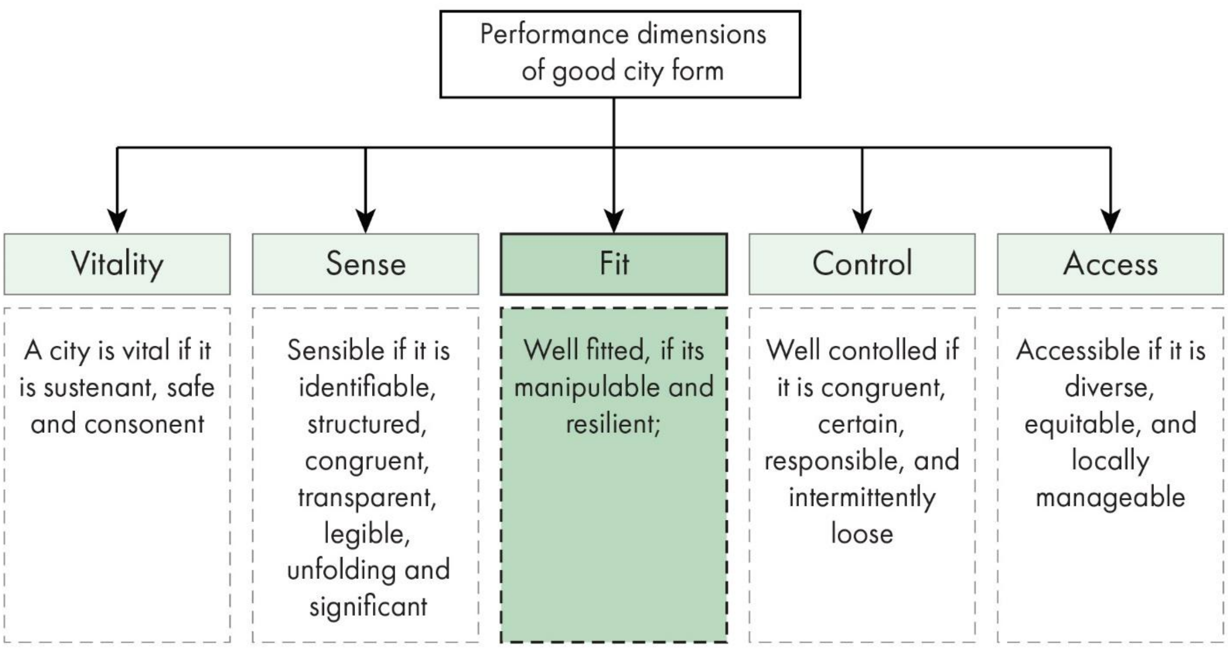


Figure 2.1 Summary of the performance dimensions (Lynch, 1981)

‘Fit’ is the ability of a form to adapt and withstand future changes in function. Lynch suggests that screening and “fine-tuning”, or in other words, “care and attention” of a place, is the key to good match or ‘fit’ (Lynch, 1981, p.161). Lynch identifies “adaptability” as one of fit’s measures that aligns with climate adaptability. This concept of adaptability for ‘fit’ complements the discussion of evolutionary resilience by Folke et al. (2010, p.25) that it broadens the description of Lynch’s dimension of ‘fit’ to incorporate dynamic interplay between persistence, adaptability, and transformability (Davoudi et al., 2013). For Lynch, the extent of adaptability extends not only to the sense of accommodating varying uses in a space but also to meet different expectations of prospective users in the future underscoring the ability to change in terms of either the physical form or function. He states, “Adaptability is a concern for all cultures. But the span of concern depends on cultural values and knowledge” (Lynch, 1981, p.170).

A more restricted measure of adaptability is manipulability, which is the extent to which either the physical form or the function can be changed/manipulated in the predictable near future. Manipulability focuses on maintaining functions for the predictable near future. It is a measure of the degree of change that could be achieved under the limits of either changing functions or form. Manipulability, as a measure of ‘fit’, is also crucial in determining the number of new functions that can or can not be accommodated with appropriate levels of intensity. Another measure of ‘fit’ is reversibility or resilience. It is the ability of the system to go back to its previous state. Through this ability of “fine-tuning”, i.e., the ability to constantly make gradual changes, a user can achieve a better ‘fit’ in his/her environment (Lynch, 1981).

This dimension of ‘fit’, along with manipulability and resilience, is highly relevant to climate mitigation, adaptation, and resilience objectives as discussed in section 2.1 in a sense that they allow for “transformative” and “progressive” change while also promoting general adaptability.

Therefore, these dimensions of ‘fit’ provide a theoretical base for understanding how the physical city form can be better adapted to changing conditions. However, this theory seldom touches on the environmental aspects/ spatial quantitative analysis and arrangement of the city form. In other words, this theory does not necessarily provide information on how the urban processes and natural environment can be better fitted to increase the overall resilience.

2.4.2 Adding McHarg to the equation

Complementing Lynch’s dimension of ‘fit’ for climate adaptation is Ian McHarg’s (1969) concept of ‘physiographic determinism’. The combination of these two theories captures the whole breadth of climate adaptation to include urban landscapes as a part of the whole equation. This completes Lynch’s framework and establishes a more holistic definition of resilient city form as a “learning ecology”. Figure 2.2 illustrates the theoretical framework of this study.

In his book *Design with Nature* (1969), Ian McHarg recognizes the importance of natural ecosystems in urban landscapes by exploring relationships between the built environment and the natural environment, serving as an environmentally conscious approach to land use planning. *Design with Nature* (McHarg, 1969) focuses on the spatial relations between patterns of land use and urban morphology. This relation is bent on preserving the natural landscape and its ecosystem functions, aligning with the overall concept of stream daylighting as an NbS to enhance urban resilience and climate adaptation.

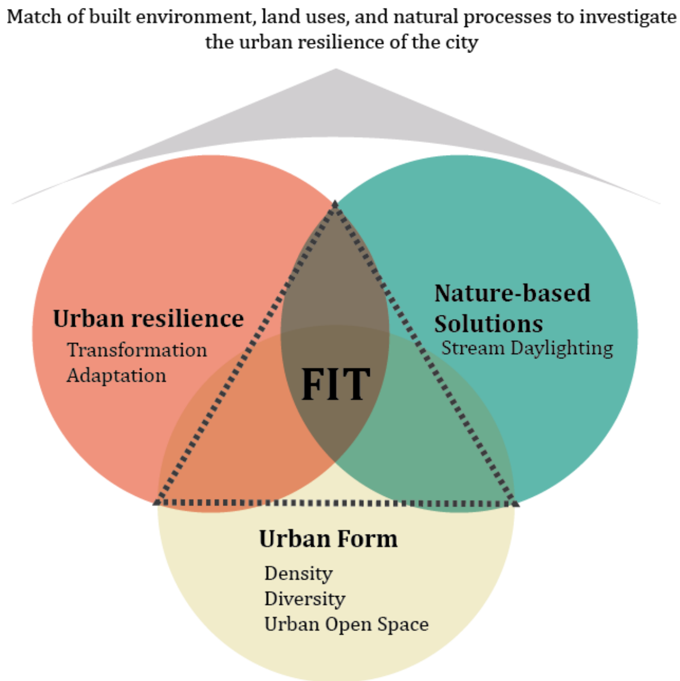


Figure 2.2 The three major concepts of investigation in the study

McHarg (1969) states that there are two systems within any metropolitan region- the pattern of natural processes (preserved in urban open space), and the pattern of urban development. He defines 'fitting' as the match of the pattern of natural processes and the pattern of urban development and that this fitness must embrace both natural and artificial objects in the environment (ibid). The main concepts of importance from McHarg (1969) in this study that relates to urban form and natural processes are: (a) '*Nature is a process*', comprising of the various biotic elements in their abiotic environments like physiography, hydrology, drainage, climate, soil, vegetation, wildlife habitat, and land use, and (b) *Physiographic/ Ecological determinism*- the process of ‘fitting’ the natural features and ecological processes and services that benefit both humans and the ecosystem (McHarg, 1964, p. 24; McHarg, 1969, p. 57).

This theory of ecological determinism, devised by McHarg, was a scientific settlement strategy to impede the existing model of planning as a mere promoter of real estate development and economic growth (Daniels, 2019). This concept of ecological ‘fitting’ and the ‘fit’ dimension by Lynch provides a necessary base for understanding city form as a whole, including the natural process to improve urban resilience.

2.5 Urban form elements

While the previous sections highlighted the literature discourse on resilience, NbS and climate change, this section highlights the importance of considering urban form as an important determining factor to achieve resilient urban development.

However, to assess climate adaptation strategies further, it is vital to analyze the various elements responsible for promoting climate resilience. Urban form is composed of numerous interconnected and independent elements, and the complexity of interactions among those elements, as well as a series of spatio-temporal feedbacks, influence the resilience of urban form. This makes defining resilience for urban form a challenging task. Using feature-based urban form attributes to quantify climate adaptiveness (Sharifi, 2009) is regarded as a good indicator as it contains features that hold unique characteristics of city form. Table 2.1 extracted from Sharifi (2019) shows the major approaches for classifying the constituent elements of urban form.

Table 2.1 Major approaches for classifying urban form (Sharifi, 2019)

Approach	Elements	Sources
Perceptual	'Paths', 'edges', 'districts', 'nodes', and 'Landmarks'	(Lynch, 1960)
Bipartite	'Built environment' and the 'transport network'	(Silva, Oliveira, & Leal, 2017)
Feature-based	Density, diversity, connectivity, spatial distribution, design, and accessibility	(Bourdic, Salat, & Nowacki, 2012; Lynch, 1981; Tsai, 2005)
Tripartite (Conzenian/ English School)	'Streets', 'plots', and 'buildings'	(Conzen, 1960)
Hierarchical (Canniggian/ Italian School)	'Structures', 'systems', and 'organisms'	(Caniggia & Maffei, 2001; Kropf, 2014; Stangl, 2014)

The internal texture of a settlement/ city holds a lot of information on the urban morphology and structure of the city. Lynch (1981, p.274) determined that three principal features define the internal texture of a city, namely, density, grain, and access and that by measuring these characteristics, its performance might be judged. Moreover, Alberti (1999a, 1999b), while investigating various impacts that specific urban patterns have on ecosystems, identifies density, connectivity, grain, and urban form as the urban parameters that determine the environmental performance and the degree of impact of built form on urban environments, argues that these parameters positively affect the resilience of cities and the surrounding landscapes (Alberti and Marzluff, 2004; Alberti et al., 2003; see also Alberti, 2005). Additionally, in their report, IPCC

(2014)identifies four key urban form metrics, namely density, land-use mix, connectivity, and accessibility, claiming that these parameters effectively describe the relationship between energy and GHG emissions, and built form. While IPCC's metrics are predominantly about mitigation, it is relevant to this study as these metrics can also be used to describe climate adaptation, as described in the sections below.

These feature-based urban-form attributes hold much information on the urban form characteristics of the city. Table 2.2 summarises a list of studies using feature-based attributes to judge the climate performance of the urban form.

Table 2.2 Summary of feature-based studies in literature

Urban from attributes	Climate theme	Reference
Neighbourhood shape and size, neighbourhood density, land use mix, lots, urban blocks, urban open spaces	Resilience	(Sharifi, 2019)
Compactness and dispersion of urban form	Sustainability	(Aburas et al, 2018)
Diversity, connectivity, redundancy, modularity, and efficiency	Resilience	(Feliciotti et al, 2016)
Complexity, centrality, compactness, and porosity	Sustainability	(Sadowy, 2016)
Density, land use mix, connectivity, and accessibility	Urban form and climate change	(Seto et al, 2014)
Density, diversity, green areas, compactness, passivity, shading, orientation, connectivity, accessibility, centrality, design, proximity to public transport, and hierarchy	Urban form and energy	(Silva et al, 2017)

Heterogeneity, shape complexity, core area analysis and density	Sustainability	(Behnisch, 2012)
Intensity, distribution, proximity, connectivity, complexity, diversity, and form.	Sustainability	(Bourdic et al., 2012)
Harmony with nature, latency, polyvalent spaces and diversity, indeterminacy, heterogeneity, modularity, and connectivity	Resilience	(Dhar & Khirfan, 2017)
Density, Housing/building type, layout, land use, transport infrastructure	Form elements and socio-economic characteristics	(Dempsey et al, 2010)
Density, diversity, and design	Built environment and travel demand	(Cervero & Kockelman, 1997)
Compactness (in terms of density, mix, and intensity)	Social sustainability	(Burton, 2002)
Compactness, Porosity, Diversity, and landscape metrics	Sustainable urbanization	(Guan, 2018)
Complexity, centrality, compactness, porosity, and density	Sustainable development	(Huang et al, 2007)
Density, centrality, accessibility, and neighbourhood mix	Spatial metrics	(Ewing et al, 2002)
Metropolitan size, density, unequal distribution, centrality, and continuity	Compactness vs. Sprawl	(Tsai, 2005)
Urban Density	Mitigation and adaptation to climate change	(Dodman, 2009)
Zonal diversity and socio-economic diversity	Diversity and spatial patterns (no link to climate adaptation)	(Talen, 2005)

These urban form attributes are interdependent, and pursuing one in isolation is insufficient in evaluating its climate performance. However, these metrics combined are arguably more effective in judging the climate performance of the built form. Based on Table 2.2, the most recurring attributes relevant to this study are density, diversity, and urban open spaces (see Figure 2.3). Although access is also relevant, it is omitted in this study and can be used as a future research possibility, looking at the whole transportation system with transportation policy and modal mix, among others. Operationalizing these elements establish the necessary empirical base of this study to evaluate the climate performance of urban form in the face of daylighted streams as a nature-based solution.

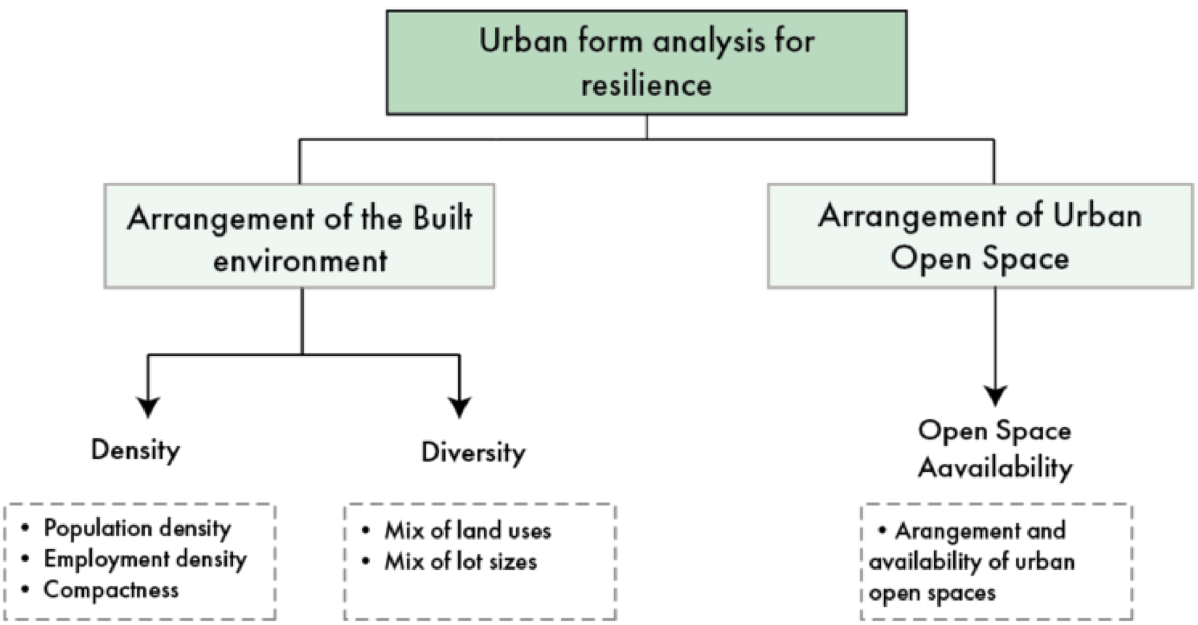


Figure 2.3 Urban form elements considered in the study

2.5.1 Density

Density, one of the most studied and key aspects of urban form, helps define, predict, and regulate the use of land (DETR, 1998). It is an outcome of the competition between land uses and its associated patterns of accessibility (Dempsey et al., 2010). The two most commonly perceived definitions of density are the density of the built environment and the density of people living or working in a given area (Porta et al., 2013; Silva et al., 2017). In simplest terms, density is the measure of an urban unit of interest (ex., population, employment, and housing) per unit area (ex., block, neighbourhood, city, and nation). It is a tool commonly used to measure the feasibility of public transport, and the suitability of certain land uses, particularly lands that provide services to the neighbourhood, like commercial, retail, or institutional (Dempsey et al., 2010).

Density has a variety of advantages on transportation planning, land/resource use management, green space uses, as well as economic and energy benefits. Furthermore, density is essential in achieving sustainable development (DETR, 1998; Haughey, 2005; Jenks & Dempsey, 2005; Jenks et al., 1996; Owen, 2009; Urban Task Force, 2005; Williams, Burton, & Jenks, 2000) and in mitigating and adapting to climate change (Williams et al., 2010; Boyko and Cooper, 2011).

Compactness, one of the most studied variables under density, is often discussed and recommended as a feature of sustainable city form (Burton, Jenks and Williams, 2003; Burgees, 2000; Sadowy, 2016). Compactness can be defined as high-density monocentric development (Gordon and Richardson, 1997) or as concentrations of employment and housing along with a good mix of land uses (Ewing, 1997). Galster et al. (2001) described compactness as the degree to which development is clustered, minimizing the amount of land developed in each square mile. Regardless of the various definitions, a recurring theme is that compactness involves the concentration of development (Tsai, 2005).

2.5.1.1 Effects of density on blue-green infrastructure

Even though commonly associated with transportation planning, density can also be used to determine the pressure that urban populations and activities lay on the urban landscapes. Density measures are also essential in maintaining place vitality, as it supports high levels of diversity in terms of population and building typologies (Ye, Li, & Liu, 2018). However, the relationship between density patterns and the pressure on the urban landscape is unknown. Intuitively, density is a good predictor of the pressure on urban landscapes in growing cities (Alberti, 2008).

Density is most commonly used as a metric in mitigation strategies to reduce energy demands and increase efficiency. A common misconception about building density is that it can only be achieved by clustering high-rise buildings together (Seto et al., 2014). It is disputed that medium-rise (less than seven floors), with high building footprints, can achieve greater energy efficiency than high-rise buildings, with low footprints (Picken and Ilozor, 2003; Blackman and Picken, 2010; Cheng, 2009; Salat, 2011; Seto et al., 2014). In other words, high density, high-rise developments imply high energy usage in terms of vertical circulation, HVAC, as well as lighting due to low passive volume ratios (Ratti, Baker, & Steemers, 2005). Therefore, there are trade-offs between building height and spacing between buildings when planning for sustainable densities. While these are mitigation strategies to avoid human interference in the climate system, they help understand how density can play a role in climate adaptation by reducing the vulnerability of the urban form to changing climates.

2.5.1.2 Operationalizing density for urban resilience

Several density measures have been used in the past, and the most common measure of urban patterns is population density and job density (Alberti, 1999b). However, density does not only concern the number of dwelling units or the population but the quantity of services and amenities. Therefore, to get a holistic understanding of the effects of density on the urban landscape, and to measure its relation to the blue-green infrastructure, several density measures involving compactness and intensity of development must be employed to get a more robust measure of density (Jenks & Dempsey, 2005; Dempsey et al., 2010).

To measure the compactness of built form, variables such as *population density* and *employment density* are used (expanded in chapter 3). In this study, density is used as an indicator of the intensity of development measured in terms of population and employment density. These variables express the intensity and compactness of the settlement in relation to the pressure on non-buildable land. As Pont and Houpt (2007, p.144) state, “only when density is seen as a composite of aspects, such as intensity, compactness, height, and spaciousness, can it be satisfactorily used to differentiate between urban fabrics, understand their characteristics, and design guidelines for future developments.”

Evidence from several studies claims that compact and walkable neighbourhoods that have reasonable access to employment and urban amenities have a positive influence on urban resilience (Carpenter, 2015; Hachem, 2016; Seelig, 2011) by reducing energy demands and promoting active transportation modes (Durand et al., 2011; Hamin & Gurran, 2009; Jackson, 2003; Lehmann, 2016; Sharifi, 2019b). However, it should be noted that extreme densities can also be detrimental to society as they can intensify Urban Heat Island effect (Dugord, Lauf, Schuster, & Kleinschmit, 2014; Hubbart et al., 2014; Hui, 2001; Sharifi, 2019b). Additionally, it is also important to note that increased densities may be achieved at the expense of good urban open space which, reducing the absorption capacity in cities as open spaces enhance flexibility and multi-functionality (Sharifi, 2019b), which is an important aspect of urban resilience.

Boundaries play a vital role in understanding density as a relationship between urban patterns and land development by excluding certain areas depending on the biophysical and socio-economic factors, specifically the presence of open water or non-buildable land (Zielinski, 1979; Alberti, 2008). Hence, it is of utmost importance to consider the boundaries and land area for the specific study subject.

To this end, density is a complex and substantial issue with many connections between the performance dimension of ‘fit’ and climate adaptation, having real impacts on the adaptive capacity, which must be traced out in any given settlement/city (Lynch, 1981, p.265). Moreover, compactness alone cannot provide significant resilience benefits. However, compactness promoted in combination with other measures such as walkability, land use mix, accessibility to employment and urban amenities, and availability of urban open space can positively impact urban resilience (Sharifi, 2019b).

2.5.2 Diversity/ mix

The *grain* of a settlement is another important dimension that is often perplexed with density (Lynch, 1981, p.265). Grain refers to the ways in which the various elements (like activities, building types, persons) of a settlement are fused together in space. In other words, grain describes the diversity in the spatial sense in a settlement. Jacobs (1969) first referred to grain with respect to the socio-economical aspects of the city, but Lynch (1981, p.265) expanded it to explicitly describe it as a spatial feature of the city, stating that “the grain of a settlement is another fundamental feature of its texture, a feature often confounded with density”. The term grain here means how various elements of a settlement are mixed in space. By the term grain, I mean the way in which the various elements of a settlement are mixed in space. These elements could be activities, building types, persons, or other features. Change or transformation is extremely relevant to urban grain as it results from constantly changing social, economic, and environmental contexts (Kostof, 1991; Norton, 2016). This is highly relevant to climate adaptation and resilience because diversity can reduce a city’s vulnerability in adverse conditions.

The elements of urban form are constantly changing and evolving at different rates relative to their respective levels of ‘stability’ (Carmona et al., 2003). Land uses are at the bottom of the hierarchy because they are the most unstable elements in the physical city form, followed by buildings, which have a shorter life span than other elements of urban form (i.e., plot, block, and streets) (Norton, 2016).

2.5.2.1 Effects of mix on blue-green infrastructure

As a spatial concept, diversity is widely used to describe place vitality in cities and is often associated with economic and social perspectives. As Montgomery (1998, p.98) finely states, “the simple truth is that the combinations of mixtures of activities, not separate uses, are the key to successful urban places”. According to Jacobs (1961, pp.161-164), there are two types of mixed-use diversity: primary uses that bring people to specific places, acting as a ‘people attractor’ such as offices, residences, shops and services, and secondary uses of diversity, which refer to the services and enterprises that grow in response to the primary uses. Further, it is important for the mix to not only occur within the development site but spread horizontally and vertically. In a study between density, unit type and diversity, Talen (2006) found that density and diversity were positively correlated, i.e., higher densities promoted higher diversity.

Places allocated for NbS and Green-Blue infrastructure act as people attractors too. They provide recreational facilities by providing a range of formal and informal play areas, fields, and gardens, provide health benefits by masking the noise and pollution of the city. Further they also provide a sense of place and a feeling of nature within the city. Therefore, daylighted landscapes, already a primary people attractor, should be maintained and monitored to see how secondary uses emerge.

To this end, we know that urban mix matters (Cervero & Kockelman, 1997), but what defines a good measure of the mix is difficult to intercept. Grain or mixture of different elements is an important measure to explain the effects of urban structure on the landscape.

2.5.2.2 Operationalizing mix for urban resilience

Mixed-use associated with appropriate levels of density is an effective strategy to enhance walkability and reduce associated GHG emissions (Lowe, Boulange, & Giles-Corti, 2014). Mixed-use development effectively reduces household vulnerabilities to energy crisis and fluctuating fuel costs (Sharifi, 2019). The presence of social units in the neighbourhood, such as schools, small stores, shopping streets, recreational facilities, and places of worship, strengthen social capital and have a positive impact on the resilience characteristics of the neighbourhood, such as absorption, recovery, and adaptation (Carpenter, 2015).

Many argue that land-use zoning is one of the most powerful tools planners use to influence human settlement patterns. Land use mix, which refers to the diversity of land uses within an area, is an important measure of the various uses that describe a settlement's development pattern (Bordoloi et al., 2013). Here, I attempt to link land-use zoning and human diversity using Talen (2005)'s approach of a modified Simpson Diversity Index, to explicitly derive the relationships between zonal diversity in the neighbourhood and stream daylighting.

Distribution and diversity of lot sizes are crucial aspectsto enhance the cities' flexibility and adaptive capacity to reduce lock-in effects. Smaller lot sizes with appropriate levels of density enable the accommodation of more open spaces and parks that provide necessary ecosystem services to the neighbourhood (Bruwier et al., 2018; Byahut & Mittal, 2017; Sharifi, 2019). The mixture of lot sizes is also an effective way of promoting mixed-use development. Ideally, the mixture must follow power-law distribution (i.e., a small number of large lots, medium number of mid-size lots and a large number of small lots) to ensure the flexibility and resilience of urban form to permit incremental change and adaptation (Tuura, 2014; Sharifi, 2019). To measure the diversity of built form, variables such as diversity of land uses at the lot level and the mixture of lot sizes are used in this study.

2.5.3 Urban open spaces

Urban open spaces are vital elements of the urban form that contribute positively to urban resilience. *Open space* is as "any unroofed ground space in the city (either natural or man-made" (Sharifi, 2019; Stanley, Stark, Johnston & Smith, 2012). Accordingly, this study recognises open space as any vacant land or land occupied by either natural or man-made features such as NbS, Green-blue infrastructure, parks, sports fields, and cemeteries.

2.5.3.1 Operationalizing urban open space for resilience

Depending on the type and configuration of open spaces, they may contribute to resilience by providing spare capacity in the city form to absorb and recover from shocks by integrating redundant open spaces into the city form (Sharifi, 2019). In addition, the availability of open space provides the city with a certain degree of freedom to accommodate future needs as and when they emerge (Allen et al., 2013; Liu et al., 2014; Sadowy, 2016). Open space in the city is also critical for enhancing the porosity of the city (Sadowy, 2016), providing multiple ecosystem services such as provisioning services (e.g., food production), regulating services (such as the regulation of microclimate, storm water management), cultural services (e.g., recreational opportunities) and supporting services (e.g., primary production and nutrient cycling. Enabling porosity through well-distributed open spaces forms a determining factor for regulating micro-climate conditions (Chen et al., 2017; Sadowy, 2016; Stangl, 2018; Sharifi, 2019). Homogeneous distribution of a variety of open spaces increases the modularity of urban form and can expedite post-disaster rescue, relief, rehabilitation, and reconstruction activities (Villagra et al., 2014).

2.5.4 Linking concepts and theories to empirical studies

The following section draws from the key findings of the literature review in establishing connections between the theoretical framework, i.e., indicators of fit and empirical studies concerning resilient urban form.

Table 2.3 Links between theoretical framework and empirical studies

Indicators of 'Fit'	**Measures**		
	Density	Mix	Urban Open Space
Adaptability	• **Compactness** reduces the amount of time it takes to transport people, goods, and materials positively influencing adaptability (Elkin, McLaren, and Hillman, 1991; Jabareen, 2006; Guan, 2017).	• **Mixed-use zoning** allows compatible land uses to coexist reducing travel demand (Fang et al., 2015; Neilsen, 2015; Silva et al., 2017). • **Small lot sizes** combined with appropriate densities	• Well-spaced open spaces are a deciding factor for regulating urban micro-climate conditions, which is an effective climate adaptation strategy (Chen et al., 2017; Sadowy, 2016;

	• **Compact** neighbourhoods reduce energy demands (Durand et al, 2011; Hamim & Gurran, 2009; Jackson, 2003; Lehmann, 2016). • When promoted in conjunction with land use mix, and improved access to jobs and services, **compactness** ensures maximum adaptability (Hachem, 2016). • **Compactness** of the urban form has a positive impact on environmental performance while considering possible trade-offs (Dodman, 2009). • Compact and tall building types have greatest heat-energy efficiency at the neighbourhood scale while detached housing was found to have the lowest (Rode et al., 2014)	allow for a greater proportion of land to be used for open spaces and parks services (Bruwier et al., 2018; Byahut & Mittal., 2017). • Small **lot sizes** increase percolation of rainwater that is essential for natural replenishment of aquifers, flood control, and stormwater run-off treatment (Bruwier et al., 2018).	Stangl, 2018). • The presence size and location of green areas is crucial in reducing air pollution and minimizing UHI (Nowak, 1994; Alberti, 1999). • Improving the city's porosity has a number of advantages, including improved storm water management and urban food production (Chen et al., 2017; Sadowy, 2016; Stangl, 2018; Sharifi, 2019).
Manipulability	Not Available	• Fine grained lots enable incremental evolution in response to changing climate conditions and are more suitable for building urban resilience (Venerandi et	• Availability of urban spaces provides a certain degree of freedom to accommodate new needs (Allen et al., 2013; Leon & March, 2014;

		al., 2017). • Fine-grain lots are more suitable for accommodating future changes at lower costs through incremental adaptation of the physical form to minor fluctuations and disturbances (Byahut & Mittal, 2017; Feliciotti et al., 2017; Marcus & Colding, 2014; Salat, 2013; Salat, 2017; Whitehand, 2001). • Power-law distribution of lots ensures diverse range of building types making the urban form more flexible to permit incremental changes to adaptation (Tuura, 2014).	Liu et al., 2014; Sadowy, 2016). • Connected network of open spaces provide for redundancy (Sharifi, 2019).
Resilience	• **Compact** and walkable neighbourhoods that have access to employment and urban amenities have a positive influence on urban resilience (Carpenter, 2015; Hachem, 2016; Seelig, 2011).	• Presence of social networking entities such as schools, small stores, shopping streets, recreational facilities, and places of worship in the neighbourhood support strengthening **social capital**, is demonstrated to have positive impacts on absorption, recovery, and adaptation capacities of the communities (Carpenter, 2015)	• Homogeneous **distribution of open spaces** (of heterogeneous type and size) increases modularity of urban form and is argued to expedite post-disaster rescue, relief, rehabilitation, and reconstruction of activities (Villagra, 2014)

2.6 Summary

The main purpose of this chapter was to investigate the literary discourse on urban resilience, Nature-based solutions, and resilient urban form and the potential links in accessing the resilience of urban form in the case of Nature-based solutions.

This chapter drew connections between the theoretical and empirical study by combining the indicators ‘fit’ (Lynch, 1981), i.e., adaptability, manipulability, and resilience; and ‘fitting’ (McHarg, 1969), i.e., match of urban form and natural process, with urban form-based attributes to analyze and assess the resilience of built form. It was identified in the literature review that feature-based urban form attributes hold more information about the physical city form and hence is suitable for analyzing the climate performance. Hence, feature-based urban form attributes relating to the indicators of ‘fit’ i.e., adaptability, manipulability, and resilience in the empirical study were identified as density, diversity/ mix, and the availability of urban open spaces in the city.

The definition of urban resilience considered in the study by Meerow et al. (2016) offers three dynamic pathways to a resilient state, namely, persistence- ability to resist disturbance and maintain functions, transition- ability to adapt incrementally, and transformation- ability to fundamentally and purposefully change or transform. By definition, NbS, stream daylighting in particular, can be seen as a cross between transition and transformation. It enables incremental adaptation by transforming a space by introducing blue-green infrastructure into dense urban fabrics in response to climate change.

The growing concentration of people and the reduction of open spaces in urban areas establishes the importance of NbS as an effective solution in maintaining and enhancing urban resilience to achieve global sustainability. While there is a substantial body of literature on various social, economic, institutional, and environmental dimensions of urban resilience, there has been relatively little attention paid to urban form as a factor in building urban resilience (Sharifi and Yamagata, 2018). Furthermore, empirical research has rarely connected stream daylighting and urban form (Khirfan et al., 2020), specifically in building urban resilience.

In theory, summarizing the discussion from the literature review, it is evident that compact developments with an appropriate mix of densities and uses and better provisioning of urban open spaces are highly manipulable, resilient, and adaptable to change. The following chapter draws on these conclusions to evaluate the resilience of urban form concerning stream daylighting in the city of Zürich.

Chapter 3: Methods

3.1 Background

During the last century, over 100 km of previously open streams and brooks in Zürich, disappeared from the surface due to rapid urbanization. This resulted in constraining streams to underground sewers and pipes that connected to the City's sewerage system. This meant that sewerage and rainwater run-off went into the same pipes to the waste water treatment plants. This resulted in an increased load of "clean" run-off into the drainage channel, causing increased operational costs diminishing the efficiency of the wastewater treatment process. Besides, this also resulted in the deterioration of urban landscape as rainwaters did not replenish the underground aquifers anymore, resulting in the degradation of the natural habitat and the loss of valuable public recreation areas in the city.

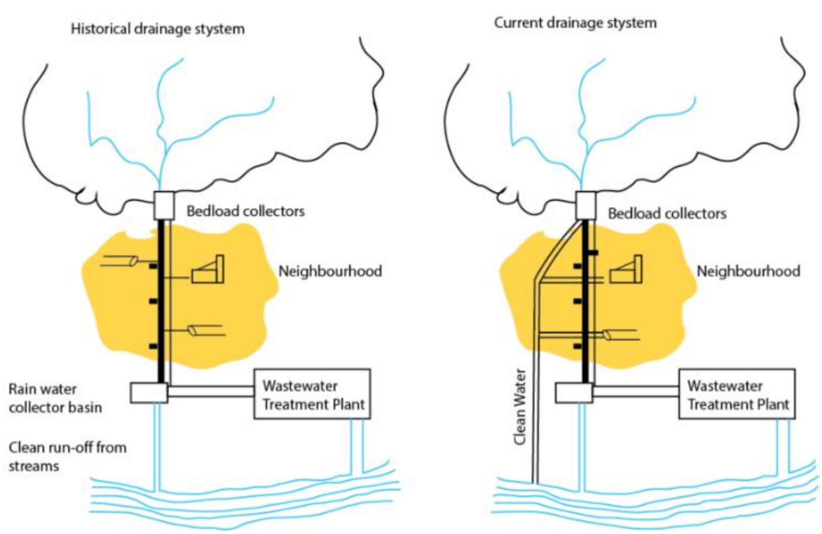


Figure 3.1 Fresh water that has previously flowed into the sewage system is now fed into a fresh-water system (Retrieved and modified from Conradin & Buchli (2004)).

As a result, an amendment to the Swiss water protection law in 1991 stipulated that clean rainwater run-off water must directly seep into the ground to replenish the underground aquifers, or where this is not possible, must be directed into the stormwater drainage system separated from the wastewater drainage system (Conradin & Buchli, 2004). Accordingly, stream daylighting emerged as a part of the new drainage concept, which stipulated that the streams formerly culverted must be reintroduced into the urban fabric by daylighting.

Article 7 (Disposal of waste water) of the Waters Protection Act (1991) states that *"non-polluted waste water must be discharged by infiltration according to the instructions of the cantonal authority. If local conditions do not permit this, such non-polluted water may be discharged into surface waters; in this case retention measures must be taken if possible, so as to ensure a steady discharge in the event of high inflow. The discharge of water that is not shown on a communal drainage plan approved by the canton requires the consent of the cantonal authority".*

Zürich's stream concept called "Bachkonzept" came into effect in 1988 as a part of the Swiss Water protection law. The main objective of the daylighting program in Zürich was to avoid the diversion of stream water into the sewers, leading to the idea of reopening and revitalizing brooks and streams and using them as a part of a separate clean water system (Conradin et al., 1998).

The concept was introduced to improve the recreational qualities of urban neighbourhoods, to restore lost habitat, to enhance the relationship between humans and the natural environment and to increase the efficiency of the wastewater treatment process by channelling clean rainwater through water channels in the form of brooks or streams (Conradin et al., 1998). As a result, in more than 40 projects, about 21 km of streams or stream sections were revitalized and daylighted (Khirfan et al., 2020a). In May 2003, the City of Zürich was awarded the Water Price of Switzerland for its successful stream concept (Entsorgung und Recycling Zürich (ERZ), 2003). However, over time, this resulted in the city's water quality improving, and daylighted streams became a part of the public realm design.

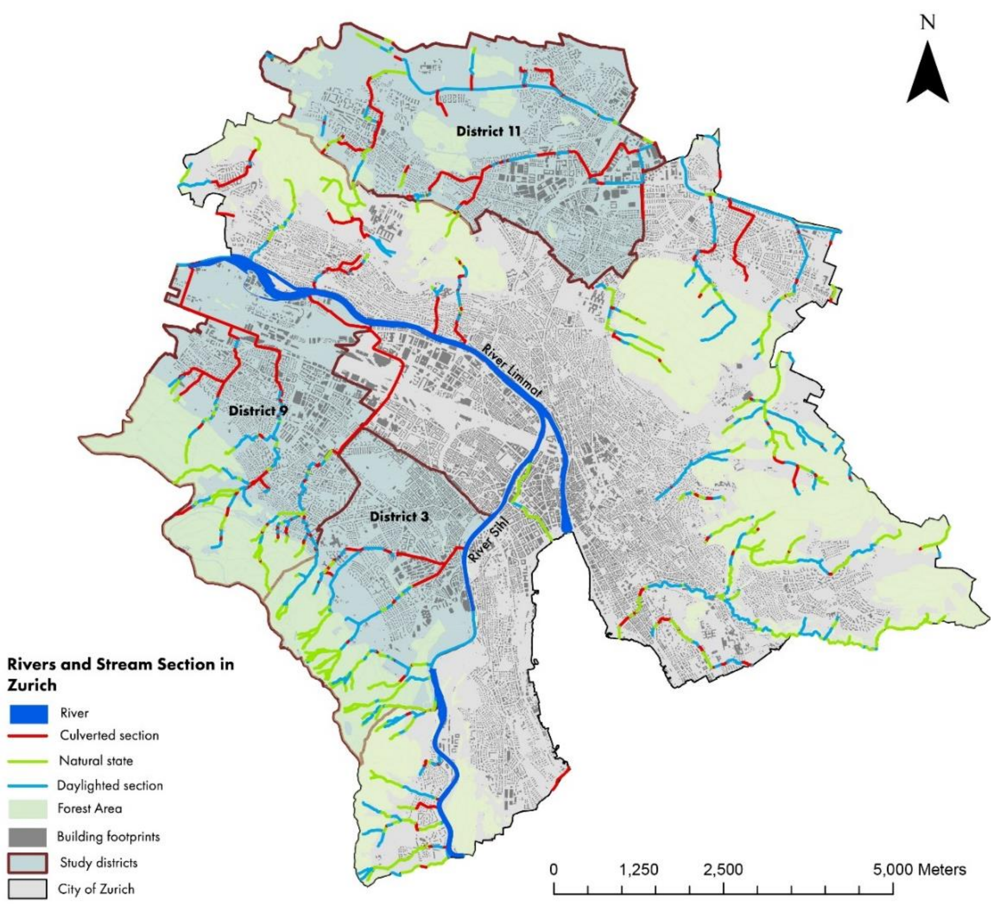


Figure 3.2 Stream sections in the City of Zürich

3.1.1 Process of stream daylighting in Zürich

Streams in the city of Zürich were turned into culverts primarily due to the increasing densification of the settlement area to accommodate the growing population. As the settlements continued to grow, more sewerage from the settlements was thrown into the open streams together with waste water and clean water, polluting the streams. Thus, as a result, the streams were channelled into underground culverts to sewage treatment plants (Broadhead et al., 2013; Conradin and Buchli, 2005). In addition, other non-polluted water sources were also connected to the sewage treatment plant, including runoff water, water from wells, and cooling water from industrial plants (ERZ, 2003). This resulted in increased operational costs reducing the efficiency of the wastewater treatment plants reducing the city's blue infrastructure. As a result, the City of Zürich decided to revitalize brooks and streams to their natural state in the city implementing the stream daylighting concept to reduce the clean water runoff going into the pipes.

In Zürich, the essential criterion for daylighting stream sections is a considerable accumulation of rainwater and spring water in undeveloped areas or as part of a rehabilitation project in highly developed urban areas (ibid). In Zürich, the decision to daylight a stream is based on one of the three ways based on the preceding criteria:

a) **Active planning by authorities**, in which city planners collaborate closely with landowners to redefine land boundaries and select suitable parcels for cooperative development.

b) **Initiative from the department of drainage, ERZ Zürich**, where authorities identify areas where a stream can be formed with unpolluted wastewater. In this case, streams are first exposed along roadways, and surrounding landowners are contacted to broaden the project to include more open space along stream sections.

c) **Stimulus from private sector,** where older members of the settlement recall a stream that once ran above ground, they can contact the authorities to have the stream uncovered as part of the settlement's rehabilitation, along with walkways and playgrounds.

Additionally, a nursing concept is also established when a stream is daylighted, in which the different sections of the stream are distinguished by a unique design of the creek bed and planting. The stream and the surrounding green spaces create a natural equilibrium in the neighbourhood, providing socializing opportunities for the residents of the community (ERZ, 2003). In densely populated places, waterfront areas provide ecosystem services that are quite scarce, and they operate as a catalyst for new habitat, improving the settlement's overall living quality.

3.1.2 Ecological planning goals in Zürich

Since 2007, the City Council has been aligning its long-term actions with overarching plans known as the "Zürich 2025 strategy" in order to preserve the City's characteristics in a rapidly developing environment. In 2016, the 2025 strategy was updated with the publication of a new document titled "Zürich Strategies 2035", which provides the City Council with long-term direction and orientation for its actions to identify opportunities for improvement.

One of the sustainable growth strategies in Zürich is densifying settlements in a "**socially responsible and ecologically compatible way** with a wide range of housing" (Zürich City Council, 2016, p.7). The city of Zürich is growing with an expected population increase of 80,000 persons by 2040 (ibid), and a part of the plan is to direct 80% of that growth in urban regions. In this view, a central strategy of the municipal structure and utilization plans is **high-quality densification** of the existing residential areas preserving the inherent identity of the city's neighbourhoods. This strategy focuses on the quality of life for residents, with well-equipped infrastructure, good local amenities, reliable municipal services, and attractive leisure areas. It is a precautionary measure to preserve the environment and provide a high quality of urban development.

In this context, stream daylighting has a significant potential to enable ecological and sustainable growth by increasing the city's urban resilience by providing enhanced ecosystem services in dense urban areas without compromising the unique character of the neighbourhoods.

3.2 Study Area

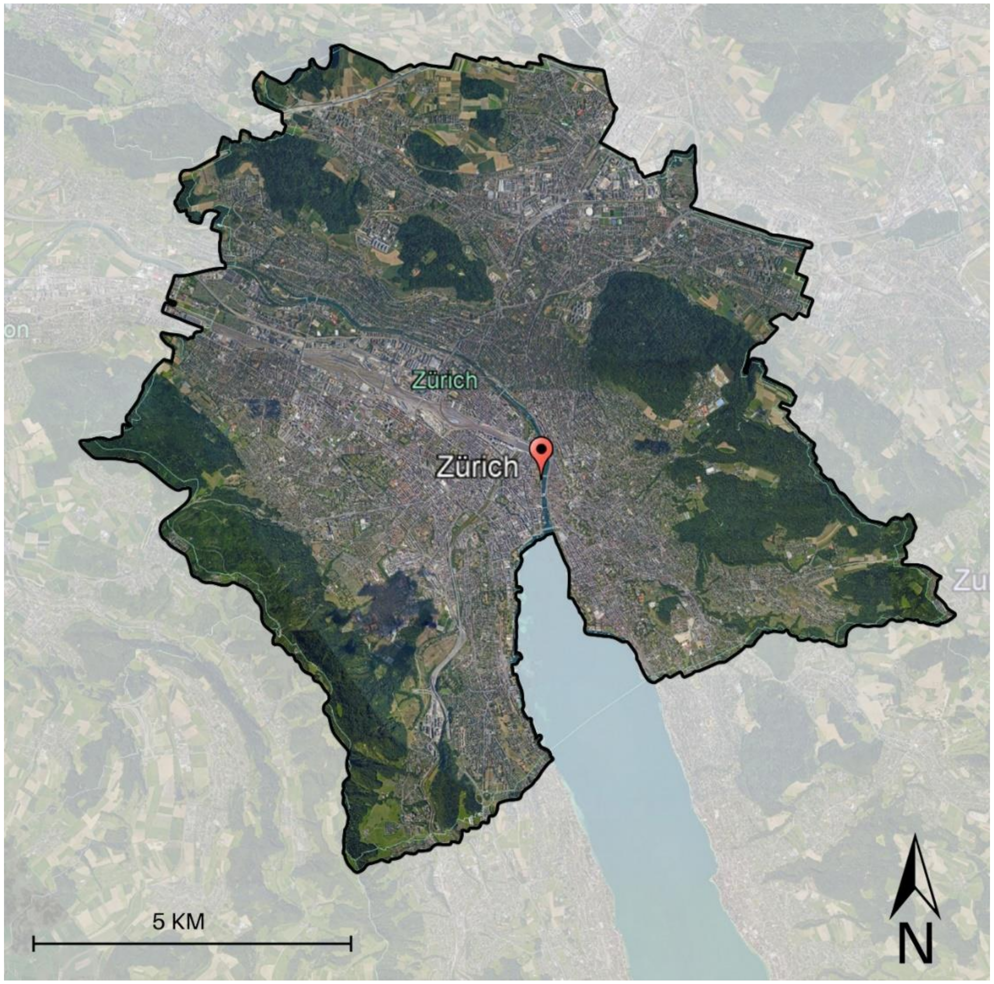


Figure 3.3 Aerial map showing the City of Zürich

Zürich, the largest city in Switzerland, is situated in the north-western tip of Lake Zürich. Switzerland has a long history of human habitation, defining landscapes and land use patterns (Price et al., 2015). With an area of about 88 Km^2, the city of Zürich hosts a diverse population of over 400,000 inhabitants, with 32% foreign nationals coming from 169 countries and 61% residents with migration background in the last 15 years (City of Zurich, 2014; 2015).

3.2.1 District profiles

Figure 3.4 Districts in the City of Zürich

The City of Zürich has 12 districts (known as *Kreis* in German), numbered 1 to 12, and 34 neighbourhoods (known as *Quarters*), with each district containing between one and four neighbourhoods.

For this study, streams daylighted in Districts 3, 9 and 11 are selected to analyze the relation between built form and open space and daylighting (as shown in Table 3). These were selected based on the following criteria that:

1. The districts have experienced enormous population growth (11%, 26% and 40% growth rate since 2000 in Districts 3, 9 and 11, respectively).

2. The districts have comparatively similar district profiles in terms of land uses (predominantly residential), population numbers and comparable land area.

3. The streams daylighted predominantly run through the residential areas in the districts with over 800 m of stream daylighted, and

4. The availability of geospatial data that clearly distinguished daylighted stream sections from culverted stream sections and the data described in Section 3.3 was available.

Table 3.1 District profiles

	Zürich City	**District 3**	**District 9**	**District 11**
Population	434,008	51,122	56,637	75,804
Land Area (Km^2)	87.93	8.65	12.1	13.4
Population density (number of people/km^2)	4700	5303	3770	5085

Data Sources: Resident population: BVS, 2019; Proportion of foreigners: BVS, 2019; Population density: BVS, 2019

District 3, a predominantly residential district known as ***Wiedikon,*** has three quarters *Alt-Wiedikon*, *Sihlfeld* and *Friesenberg.* The district hosts numerous cafes and restaurants with good public transport access and natural recreation areas. District 9 is composed of the Quarters *Albisrieden* and *Altstetten*. Both neighbourhoods were formerly small farming villages, with *Altstetten* hosting the city’s largest and most populous neighbourhood. While the rural settlement structures in *Altstetten* have disappeared, the rural character of *Albisrieden* is still preserved. The district is predominantly a residential area with a high share of social housing and many green open spaces. District 11, also called Zürich Nord, is Zürich's northernmost district with a rural character. The district contains quarters *Affoltern*, *Oerlikon* and *Seebach*.

3.2.2 Study streams

The study considers streams daylighted within districts 3, 9 and 11 detailed in Table 3.2 and Figure 3.5.

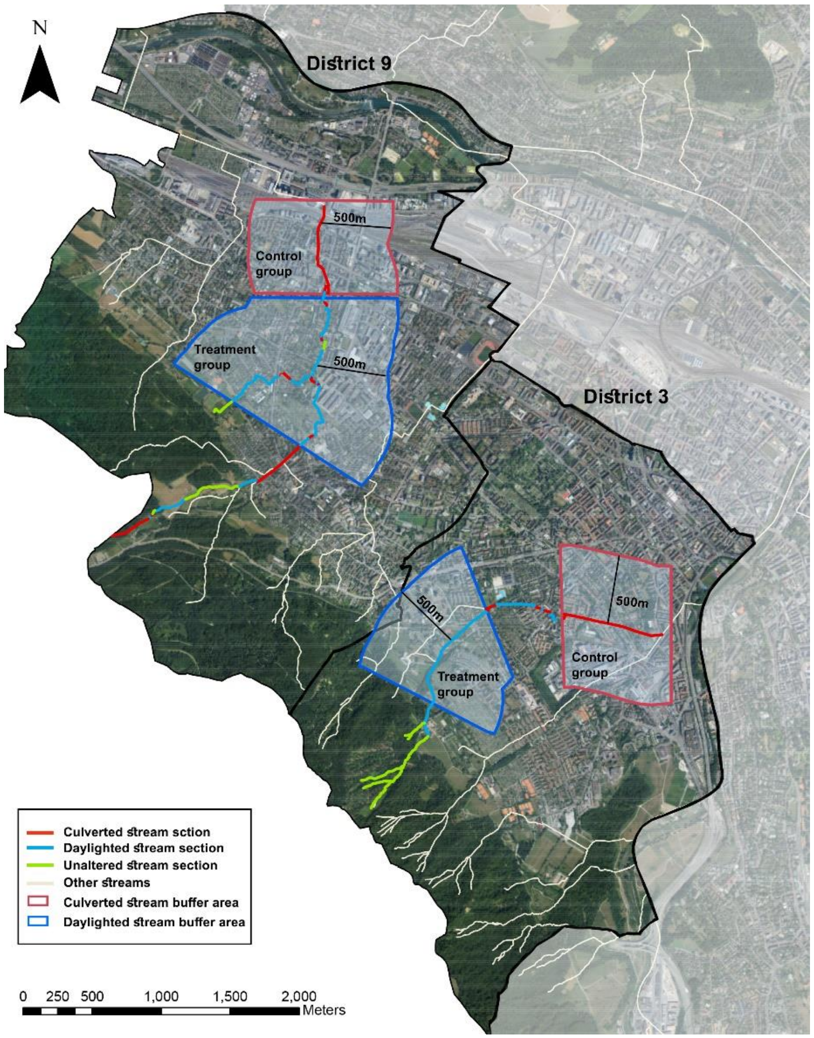
Table 3.2 List of daylighted streams considered in this study (ERZ, 2003)

No.	Daylighted stream and its tributaries	Total length daylighted (m)	Year daylighted (completed)	District
1	Albeisreider Dorfbach	2500	1991	9
2	Binzmühlebach	800	PI: 2000; PII: 2002	11
3	Friesenbergbach	800	1991	3

Albeisreider Dorfbach, along with its six tributaries, is one of the most significant streams running through the urban fabric in the City of Zürich. It is about 11 Km in length with over 2500 m daylighted between the years 1989 and 1991. Today, the stream flows through public parks and private properties in District 9. The stream was daylighted along the old stream in place of a planned clean water pipeline.

Friesenbergbach, until 1990, flowed from the Üetliberg to the beginning of the settlement area in District 3. It is about 5.5 Km in length with over 800 m daylighted between the years 1990 and 1992. The excessive water flowing along the creek channel in addition to extensive construction activities in the settlement area aggravated flooding in the neighbourhood. Daylighting as a solution to control flooding in the area was therefore inevitable.

Binzmühlebach was daylighted over 800 m between the years 2000 and 2002. The stream originates from the catchment (forest) area of over 200 Hectares. The daylighted section of the stream flows along the Neunbrunnenstrasse through the residential settlement in District 11. Moreover, this stream helps with rainwater drainage and infiltration from the nearby residential areas.



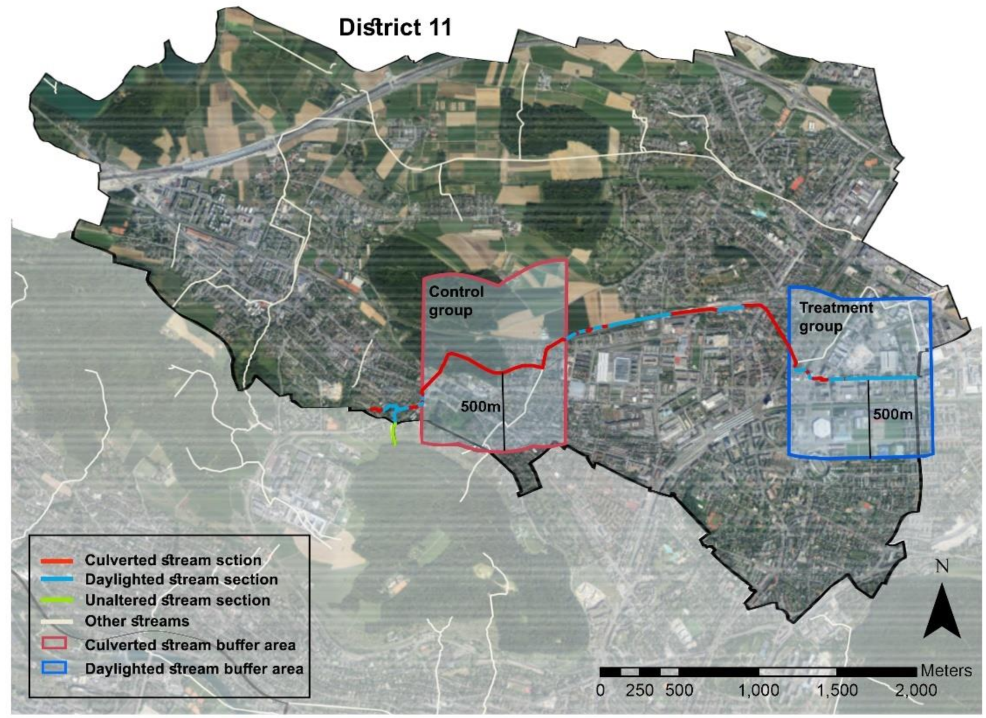


Figure 3.5 Districts 3, 9 and 11 showing stream sections and the respective control and treatment groups

3.3 Research design

This study adopts a comparative experimental approach to examine the correlation between stream daylighting and urban from with regards to enhancing urban resilience through compactness (as a measure of clustering of population and employment), diversity/ mix (diversity of land uses and mix of lot sizes), and urban open space.

In this study, the analysis takes place in two scales- at the district and local scales. This two-level analysis acknowledges the nested hierarchy of scales which is essential in analyzing urban form characterized by cross-scale dynamics. Figure 3.6 outlines the main steps and processes considered in this study.

At the district scale, the physical properties of the three districts are examined in terms of compactness, diversity, and availability of urban open spaces. Since the streams considered in this study run throughout the entire length of the districts, this scale of analysis is essential to understand the overall urban structure of the districts in which the streams are present.

To further analyze the correlation between the urban form attributes considered in this study and stream daylighting, specific areas surrounding the culverted and daylighted streams are considered. The average distance people walk to basic amenities such as schools, public transit, grocery stores, and sports fields is approximately within 500m in the city of Zürich (Lautenschütz & Jeanneret, 2017).

Accordingly, this study adopts the average proximity distance of 500m and uses this same distance to define a buffer along either side of the culverted sections and daylighted sections of the streams within the districts. As such, the control group is the 500m-buffer area surrounding the culverted sections of the stream, while the treatment group is the 500m-buffer area surrounding the daylighted sections of the stream (Figure 3.6, Table 3.3).

The stream sections within the three districts are considered based on:

1. Availability of geospatial data that distinguished stream daylighted sections from culverted sections.
2. Match between data from the Zürich stream daylighting report (ERZ, 2003) and geospatial data.
3. Continuous strip of daylighted and culverted stream sections, where a continuous strip is not possible, each fragmented section is negligible and less than 100 m in length.

Measures that summarize urban form characteristics at the district scale are first presented, followed by a description of the indices at the local scale.

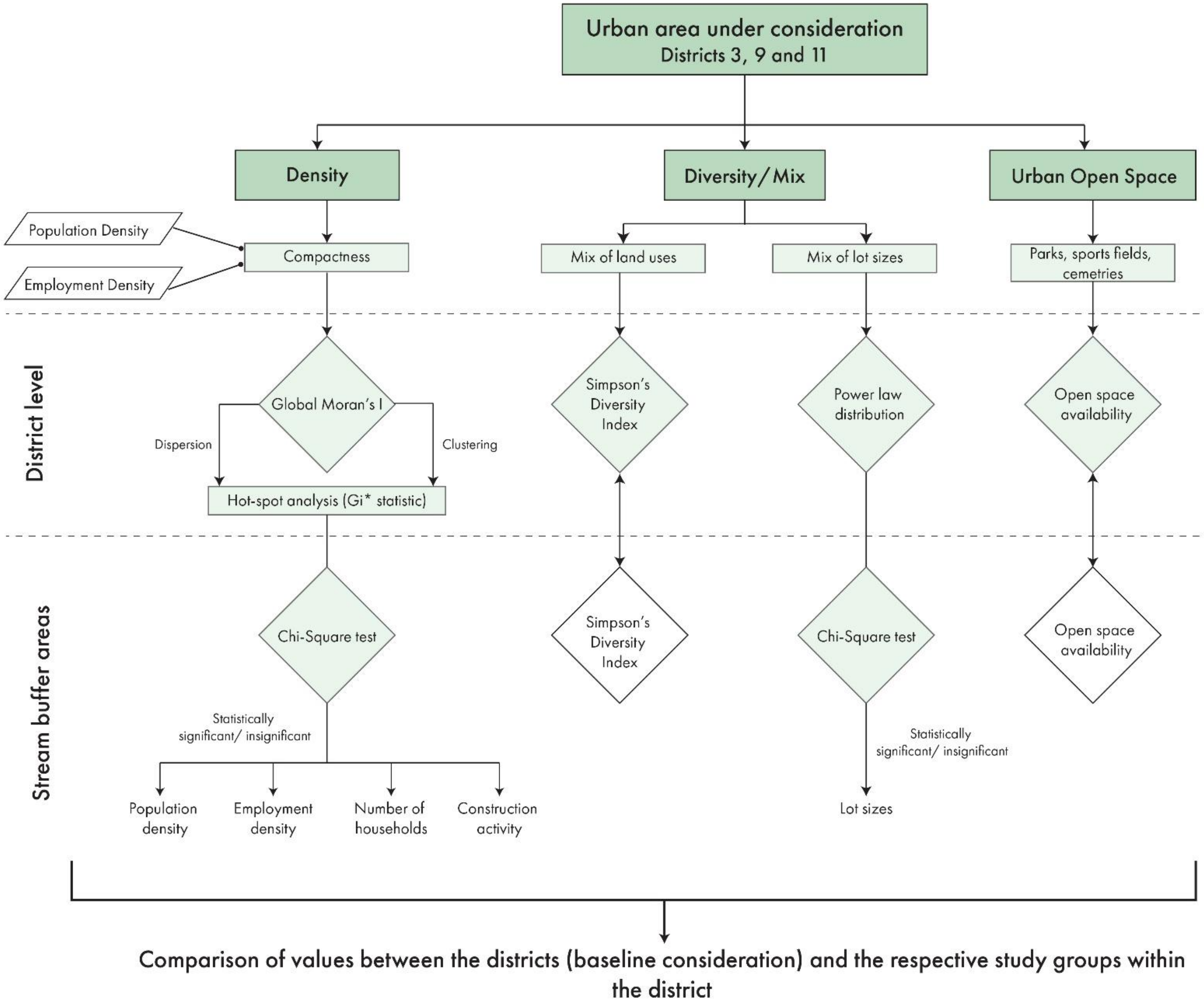


Figure 3.6 Main steps and processes in the study

Table 3.3 Stream sections within the 3 districts

No	Stream Name	District	Total length daylighted (m)	Total area of Treatment group (Km^2)	Total area of Control group (Km^2)	Daylighted length considered within treatment group (m)	Length in culverts within control group (m)
1	Friesenbergbach	3	800	0.85	0.9	700	760
2	Albeisreider Dorfbach	9	2500	1.4	0.7	1830	700
3	Binzmühlebach	11	800	0.9	1	730	760

3.3.1 District measures

This section explains the measures for characterizing urban form that enhances resilience in the three districts.

3.3.1.1 Compactness as a measure of density

The compactness of the urban form is interpreted using Global Moran's Index (Moran's I). It is expressed as

$$I = \frac{N \sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij}\ (X_i - X)(X_j - X)}{\left(\sum_{i=1}^{N} \sum_{j=1}^{N} w_{ij}\right)\ (X_i - X)^2}$$

Where, N = number of sub-areas in each district; X_i is the population or employment in the sub-area i; X_j is the population or employment in the sub-area j; X is the mean population or employment, and w_{ij} denotes the weighting between sub-areas i and j. The values X_i and X_j reflect the features of land parcels such as density, population, or other features. It is important to note that Moran’s I is not a direct measure of compactness but is an effective measure in distinguishing compactness from sprawl (Tsai, 2005). Moran’s I can distinguish spatial-structure-based compactness from sprawl, but its interpretations are sometimes complicated (ibid). Moran’s I value ranges from -1 to +1, with a higher value indicating that high-density sub-areas are closely clustered, whereas a value close to zero meaning random scattering, and a value -1 representing a ‘chessboard’ pattern of development (ibid).

Global Moran’s Index (Moran’s I) measures spatial autocorrelation to estimate the level of clustering in any given area relative to its adjacent areas. This index is determines if the population and employment density in districts 3, 9 and 11 are clustered or dispersed. Moran’s I assumes Complete Spatial Randomness (CSR), which describes the pattern of points that would occur by chance in a completely undifferentiated environment, i.e., urban development is randomly distributed across the landscape.

This measure of Moran’s I can effectively tell us if the urban form is concentrated in one or more areas within the city or the district and returns a single value for each district, which is good to interpret the overall compactness of the urban form in the districts. A positive Moran’s I value denotes that the neighbouring areas are similar in terms of development density, with higher values showing higher degrees of similarities and lower values showing lower degrees of similarities. The higher degree of similarities between the cells near daylighted stream sections shows that stream daylighting attracts people and jobs without compromising the urban open space available for its residents and reducing the Vehicle Kilometers Travelled (VKT), enhancing the climate resilience. On the other hand, lower values show that population and employment are sprawling, adding to the pressure on the open spaces in the city.

Due to the complexity of clustering, it is often difficult to observe or predict Moran's I by observing a map. Moran's I is a global statistic that captures the overall pattern of data, and not the precise location of clustering. The Getis-Ord Gi* statistic, on the other hand, is a local spatial autocorrelation that focuses on smaller regions across the spatial autocorrelation related to a particular spatial unit and identifies spatial clusters of high values (hot spots) and low values (cold spots) with statistical significance. Getis-Ord Gi* can be expressed as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j} x_j - X \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

Where x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between features i and j, and n is the total number of features and:

$$X = \frac{\sum_{j=1}^{n} x_j}{n}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (X)^2}$$

Hence, to specifically analyze if those high concentration areas are close to the daylighted sections of the streams, the Hot Spot Analysis tool (Getis-Ord Gi*) is used to identify statistically significant spatial clusters. This hot-spot analysis is a spatial clustering test to determine if some attributes are clustered in a population given its heterogeneous distribution. The analyses, run in ArcMap, returns a z-score where higher values reflect greater clustering and low values denote no clustering. This analysis lets us know if those clustered hot areas are near or far off the daylighted parts of the streams in this study. In this research, Moran's I will be computed for population density and employment density in ArcGIS using the spatial autocorrelation function, followed by the Getis-Ord Gi* statistic to identify locations of statistically significant clustering.

3.3.1.2 Diversity

Land use mix is one of the most important measures of land use development pattern, and it refers to the diversity of land uses within an area (Bordoloi, 2013). Here, I use a modified version of Simpson's diversity Index to measure the mix of land uses for Districts 3, 9 and 11.

Land use profiles are one of the most common and fundamental forms of land use analysis. Types of land uses are regulated in the land use plans in the city of Zürich, and the area is subdivided into six zones, namely: building zones, free zones, recreation zones, agricultural zones, protection zones and reserve zones. According to the Planning Act, the six building zones in Zürich are core zones, district conservation zones, center zones, residential zones, industrial and commercial zones, and zones for public buildings. For this research, I include one more land use, i.e., free zones or recreation zones, as they form a significant part of blue-green infrastructure in the city. Together, these seven land use zones are examined at the lot level for districts 3, 9 and 11.

The land use zones are described as:

i. **Central zones** *(Zentrumszonen)* are intended for dense developments which in addition to residential, offer commercial uses, service-related uses as well as administrative uses.

ii. **District conservation zones** *(Quartiererhaltungszonen)* comprise self-contained districts with high settlement quality in which their usage and structural features must be retained or expanded.

iii. **Core zones** *(Kernzonen)* include sites that are worthy of protection, such as urban and village centres that are unique and must be preserved or expanded.

iv. **The free zones** *(Freihaltezonen)* comprise of cantonal and regional free zones may be stipulated as those areas which primarily serve or include the recreation of the population to preserve the object of nature and land.

v. **Industrial and Commercial zones** *(Industrie- und Gewerbezonen)* are primarily for industrial and commercial production facilities, large-scale distribution of goods, warehousing, and transportation.

vi. **A zone for public buildings** *(Zonen für öffentliche Bauten)* is land that is assigned to meet public demands and tasks such as retirement homes, etc.

vii. **Residential zones** (*Wohnzonen*) are primarily intended for residential buildings.

Land use mix refers to the diversity and amalgamation of different land uses at a given scale. At the city scale, the mix of land uses increases the proximity of residential zones to commercial zones, business districts, recreation zones and shops. This significantly reduces the total Vehicle Kilometers Travelled (VKT) (Cervero & Duncan, 2006).

Talen (2005)'s approach of a modified Simpson Diversity Index, is used to analyze the diversity of land uses at the lot level. Simpson Diversity Index measures the probability that two individuals randomly selected from a sample will belong to the same category. The Diversity Index (D) can be expressed as:

$$D = \frac{N(N-1)}{\sum_i n_i\,(n_i - 1)}$$

Where, *N*= total number of individuals (or zones, or housing units) for all categories; and n_i= the number of individuals (or other characteristics) in the *'i'th* category. This specific formulation is a reciprocal index, allowing for a more intuitive interpretation of values where 1 represents a community with only one species or category. The higher the value, the greater the diversity, and the maximum value is the number of categories in the sample. Hence, this measure can tell us if the land uses are diverse and mixed or clustered and segregated within the districts. As such, daylighted landscapes act as primary people attractors and they, in turn, bring in secondary uses close to the daylighted landscapes.

3.3.1.3 Open space

Urban open space, especially green space, is a crucial factor of ecosystem performance in urban areas and is essential for securing the quality of life of urban dwellers and creating sustainable urban patterns (Jenks & Jones, 2010; Hayek et al., 2015). In order to examine open space in the city of Zürich as well the districts 3, 9 and 11, open space availability for the residents in the district is used.

As an indicator with practical relevance, the supply rate of public recreational area to the inhabitants on a regional scale is calculated in order to detect undersupplied areas from an overview perspective. This indicator is deployed in the standard planning practice in the city of Zürich (Grün Stadt Zürich, 2006) implementing the following formula:

$$Suppy\ rate\ of\ Green\ Space\ (in\ percent) = \frac{offer\ of\ public\ open\ space}{Demand\ of\ open\ space} X\ 100$$

A supply rate of 100% equates to $8m^2$ public open space per inhabitant, which is the guiding value declared by the City of Zürich (ibid). Public open space considered a suitable recreational area for inhabitants must have a minimum expanse of 2500 m^2. Another precondition defined by the City of Zürich is that the public open space must be within 400 m of any given lot (Hayek et al., 2015). With the actual number of inhabitants in the respective catchment areas, the overall supply rate of open space to the residents is determined for districts 3, 9 and 11. This measure can explain the availability of public open spaces for residents within the districts.

This provision of green and open spaces is calculated on the basis of demand from the population and the provision of recreational space and is a purely quantitative figure. The degree of provision is 100% when each person living in the city has $8m^2$ of publicly accessible multifunctional open space available within a radius of 400m (Grün Stadt Zürich, 2006). For this measure, green open spaces are unroofed public open spaces, such as parks, playgrounds, and cemeteries, excluding the pastures and forest areas. This specific formulation of open space availability is calculated for districts 3, 9 and 11.

3.3.2 Local measures

As described in the previous section, the analysis at the local scale is carried out based on the 500m buffer area along either side of the culverted and daylighted stream section in districts 3, 9 and 11. The control group is the area around the culverted stream segment, while the treatment group is the area around the daylighted stream segment. Urban form attributes such as density, diversity of land uses and lot sizes, and urban open space availability are assessed for each district’s control and treatment groups.

3.3.2.1 Density and building stock

Density is the measure of an urban unit of interest (ex., population, employment, and housing) per unit area (ex., block, neighbourhood, or city). Here I use population density and employment density to examine how density differs between the control and treatment groups for the three streams.

Population density refers to the number of people within a given spatial unit, whereas employment density refers to the number of employees within a given spatial unit. In this study, population and employment densities are measured as the number of persons and number of employees per hectare. Higher population densities closer to work places and services can positively correlate to resilience by reducing the energy demands and infrastructural costs.

Chi-square statistic (χ^2 test) is a statistical hypothesis test to determine if there is a statistically significant difference in population and employment density between the control and treatment groups. The null hypothesis considered for this test is that there is no significant difference between population and employment densities and the treatment of stream sections, i.e., culverted or daylighted. This test ensures if the values for population and employment density between the control group and treatment group are statistically different or not. If the test returns a statistically significant χ^2 value with a p-value of ≤ 0.05, then the null hypothesis is rejected with 95% confidence. Further, the frequencies in densities between the two groups are compared to interpret the results from the Chi-square test. In addition to population and employment density, construction activity within the two groups is compared for each of the three streams in districts 3, 9 and 11.

3.3.2.2 Diversity

A modified version of Simpson's Diversity Index and power-law function for lot sizes are used to analyze the mix of land uses and lot sizes, similar to the district scale measure. For the diversity of land uses, Simpson's Diversity Index as stated in section 3.3.1.2, is used for the control and treatment groups within districts 3, 9 and 11.

The lot (or plot) is the basic unit of urban form and land subdivision (Kropf, 2014; Sharifi, 2019). It is argued that fine-grained lots help build resilience by facilitating incremental development in response to changing conditions (Verandi, Zanella, Romice, Dibble & Porta, 2017). Lot sizes that follow power-law configuration are arguably more resilient. Here I examine the mixture of lot sizes to see if the lots follow the power-law function. Power-law refers to the relationship between two quantities, where the frequency of a component is proportional to the inverse of its size. This implies the presence of few large-size elements and many small-size elements in the system. “An inverse power law is a continuously decreasing curve, implying that many small events (in size, density or intensity) coexist with a few large events in a mathematical highly structured way” (Salat, 2017, p.113). Small lot sizes combined with moderate levels of density allow for more space allocated to streets, open spaces, and parks (Sharifi, 2019), and hence more space for blue-green infrastructure in the city.

Figure 3.7 An example of power-law distribution (Salat, 2017)

Mathematically, a quantity x follows power law if it is drawn from a probability distribution

$$p(x) \propto x^{-\alpha}$$

Where, α is the constant or scaling parameter (Clauset et al., 2009). In figure 3.7, the x-axis represents the observed size variable, usually provided in bins, whereas the y-axis represents the frequency of components of that size. This power-law relation is presented in a scatter-plot diagram with the trendline of the curve following the power function.

Power-law is used to describe a phenomenon where a small number of elements/ items are clustered at the top/ bottom of a distribution. In other words, a small amount of occurrence is common, while large occurrences are rare. Accordingly, the city is resilient if there are large numbers of small lots, medium numbers of mid-sized lots, and a small number of large lots (Turra, 2014). This distribution allows for a variety of building typologies and uses to be accommodated, increasing the overall diversity of the settlement.

A Chi-squared test is first carried out for lot sizes between the control and treatment groups, under the null hypothesis that the frequency of lot sizes do not statistically differ between the control and treatment groups. If the Chi-square turns out to be statistically significant, the null hypothesis is rejected. Further, each of the groups are examined to check if lot sizes follow a power-law function.

3.3.2.3 Open space availability

Similar to the district measure, open space availability is calculated using the same formula as mentioned in section 3.3.1.3, and the results are compared between the control and treatment groups.

3.4 Data

This study employs multiple secondary data sources, including geospatial data from the City of Zürich's open data website (https://www.geolion.zh.ch/geodatensatz) as well as data from policy documents, journal articles, organization, and publication reports. The Swiss Federal Statistical Office for Geographic Information Systems (GIS-ZH) provided the necessary GIS data in vector format for buildings, roads, parcels, land uses, stream sections that are daylighted, left in the natural state, and culverted state, waters, and public open spaces. All data was georeferenced and projected to the CH1903+LV95 coordinate system. The appropriateness of the land use and building data was cross-validated using satellite images from Google Earth. The acquired data is then processed and analyzed using the ArcGIS 10.4 software (https://www.arcgis.com).

The primary data source for empirically analyzing the urban form attributes is using the city's open data portal. This section illustrates the data types used.

Spatial Population Statistics

Fields using	1. Population (number of people) 2. Population density (number of people per hectare)
Feature type	Vector
Feature geometry	Polygon shapefiles of 100mX100m
Scale	1:5000
Year updated	2019

Employment Statistics

Fields using	1. Employees (number of employees) 2. Employment density (number of employees per hectare)
Feature type	Vector
Feature geometry	Polygon shapefiles of 100mX100m
Scale	1:5000
Year updated	2019

ÖREB cadastre - distance lines (public property restrictions)

Fields using	1. Lot area (Sq.m) 2. Blue-green infrastructure such as public parks, cemeteries, and sports fields (Area- Sq.m) 3. Generalized land use at the lot level.
Feature type	Vector
Feature geometry	Polygon shapefiles of varying sizes with lot boundaries
Scale	1:1
Year updated	2017

Ecomorphological survey of water

Fields using	1. Total length of streams (m) 2. Length of daylighted sections of the streams (m) 3. Length of culverted sections of the streams (m) 4. Length of streams left in the natural state (m)
Feature type	Vector

Feature geometry	Lines shapefiles of varying sizes
Scale	1:5000
Year updated	2020

3.5 Summary

This chapter summarized the background, context and research design used in this study, including a summary of the data used. Table 3.4 summarizes the indicators and variables used in this study by linking the theoretical concepts of adaptability, resilience, and manipulability with empirical indicators such as density, diversity, and the availability of urban open spaces.

Table 3.4 Summary of indicators and variables.

Concept	Indicator	Variable	Measure
Adaptability, Resilience, and Manipulability	**Density**	Population density	Number of persons/Ha
		Employment density	Number of employees/Ha
		Compactness	Moran's I for population density and employment density. Getis-Ord GI* for population density and employment density.
		Land use mix	Simpson's Diversity Index
	Diversity	Mixture of lot sizes	Power law function
	Urban open space	Open space availability	Open space area/ population

Chapter 4: Analysis and Discussion

The methods discussed in the previous chapter are applied to the study area, and the climate performance of the urban form and urban open space is calculated using GIS and spatial statistical tools. The results are obtained for districts 3, 9 and 11, and the results are compared, details of which are provided in this chapter. This chapter also presents a closer look at the differences in urban form attributes between the control group and the treatment group.

4.1 Density analysis

As mentioned in the previous chapter, density is analyzed as a measure of clustering of population and employment at the district scale. It is computed using Global Moran's I for population density per hectare and employment density per hectare, for districts 3, 9, and 11. Following this, Hot Spot analysis is carried out to determine the exact position of clustering in population and employment densities within the districts.

At the local scale, i.e., along the stream buffer areas, a χ^2 statistic test is first carried out to check for statistical significance between the control and the treatment group. In addition, frequencies of densities between the control and treatment groups are compared along with construction activity. Figure 4.1 outlines the mean densities in the City of Zürich as well as districts 3, 9, and 11.

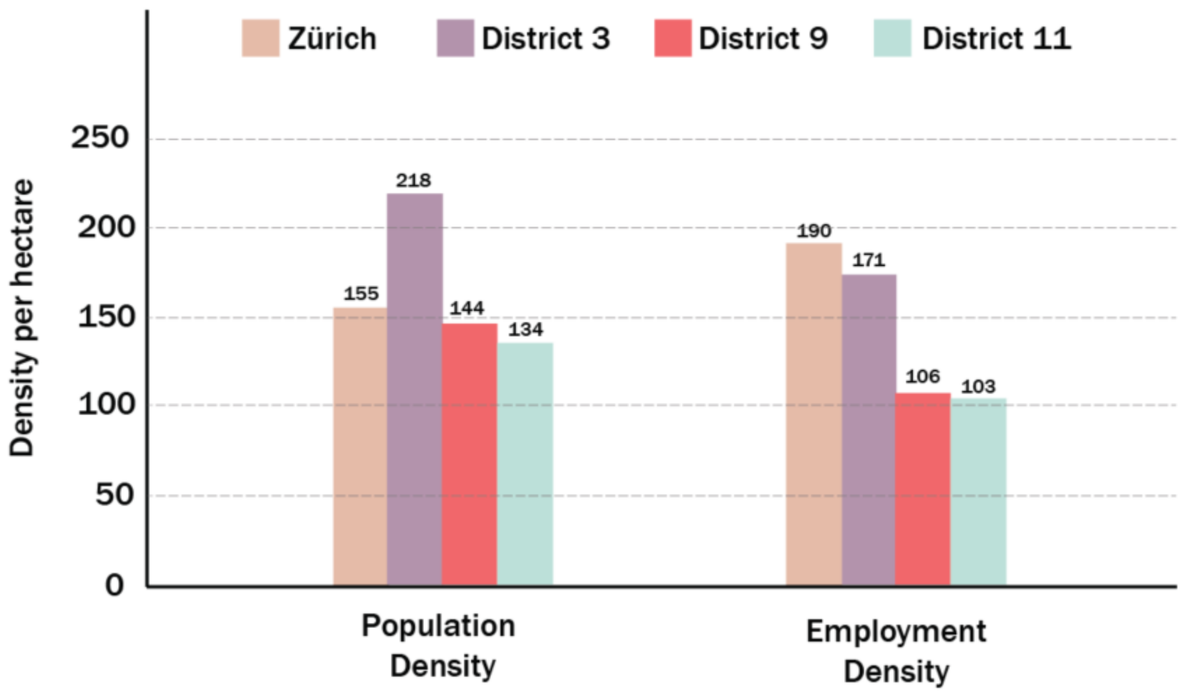


Figure 4.1 Mean densities in the City of Zürich and districts 3, 9 and 11

4.1.1 Compactness

To estimate the level of clustering Global Moran's Index (Moran's I) is used to measure the spatial autocorrelation of population and employment density. Data obtained for population and employment density is in the form of polygon square features of 1 hectare each. Table 4.1 expands on the basic summary of the data used to analyze density at the district scale.

Table 4.1 Summary stats of data used for density analysis

Variable	**Stats**	**District 3**	**District 9**	**District 11**
Population density per Ha	Total population	48793	54886	73544
	Data points (n)	358	489	681
	Mean	136	112	108
	Std. Dev.	86.96	78.47	69.73
	Minimum	4	4	4
	Maximum	387	572	408
Employment density per Ha	Total employees	40087	49620	52093
	Data points (n)	376	518	681
	Mean	109	96	70
	Std. Dev.	274.44	217.78	69.73
	Minimum	1	1	4
	Maximum	2851	1795	408

Moran's I is calculated in ArcGIS using the spatial autocorrelation function with Inverse-distance based weighting at 200m threshold distance. The choice of 200m as threshold distance is based on the raw data, i.e., 100mX100m cells, which means that every adjacent cell of a particular cell is a neighbour and is given the highest weightage, and the weightage drops with increasing distance. As such, the 200m threshold distance is considered appropriate since the main goal is to examine how clustered the density of the development is.

The analysis returns a z-score and p-value, where z-score is the standard deviation of the result and p-value is the probability that the observed spatial pattern was created by a random process. Low p-values suggest that it is improbable that the observed spatial pattern is a result of random process. P-values for each of the calculated measures were < 0.01., i.e., 99% probability to reject the null hypothesis that the observed pattern was created by random chance. Table 4.1 shows the confidence levels of uncorrected z-scores and p-values.

Table 4.2 Uncorrected critical p-values and z-scores for different confidence levels (from arcgis.com)

z-score (Standard deviations)	**p-value (Probability)**	**Confidence level**
< -1.65 or > +1.65	< 0.10	90%
< -1.96 or > +1.96	< 0.05	95%
< -2.58 or > +2.58	< 0.01	99%

Having run Moran's I for population and employment density in districts 3, 9 and 11, at a distance threshold of 200m, the result turned out with no cells having more than 1000 neighbours and no cells with no neighbours. Table 4.3 shows the values of Moran's I for population and employment density for districts 3 (D3), 9 (D9), and 11 (D11).

Table 4.3 Moran's I for compactness

Variable	District	Threshold distance (m)	Data Points	Moran's I	Z-score	P-value
Population Density	**D3**	200	358	**0.37**	12.2	<0.01
	D9	200	489	**0.21**	8.11	<0.01
	D11	200	681	**0.27**	12.54	<0.01
Employment Density	**D3**	200	376	**0.09**	3.297	<0.01
	D9	200	518	**0.35**	14.74	<0.01
	D11	200	681	**0.30**	14.29	<0.01

Based on the 200m threshold, the Moran’s I for population density for District 3 was the highest at 0.37, followed by District 11 at 0.27 and District 9 at 0.21. On the contrary, District 3 had the lowest Moran’s I for employment density at 0.09, with the highest in District 9 at 0.35, followed by 0.30 for District 11. Based on the data from the three districts and the understanding that values close to +1 represent a perfect clustering, whereas values close to 0 represent random scattering, and values close to -1 represent a chessboard pattern (Tsai, 2005), Figure 4.2 represents the approximate interpretation of Moran’s I to represent sprawling and compact urban form.

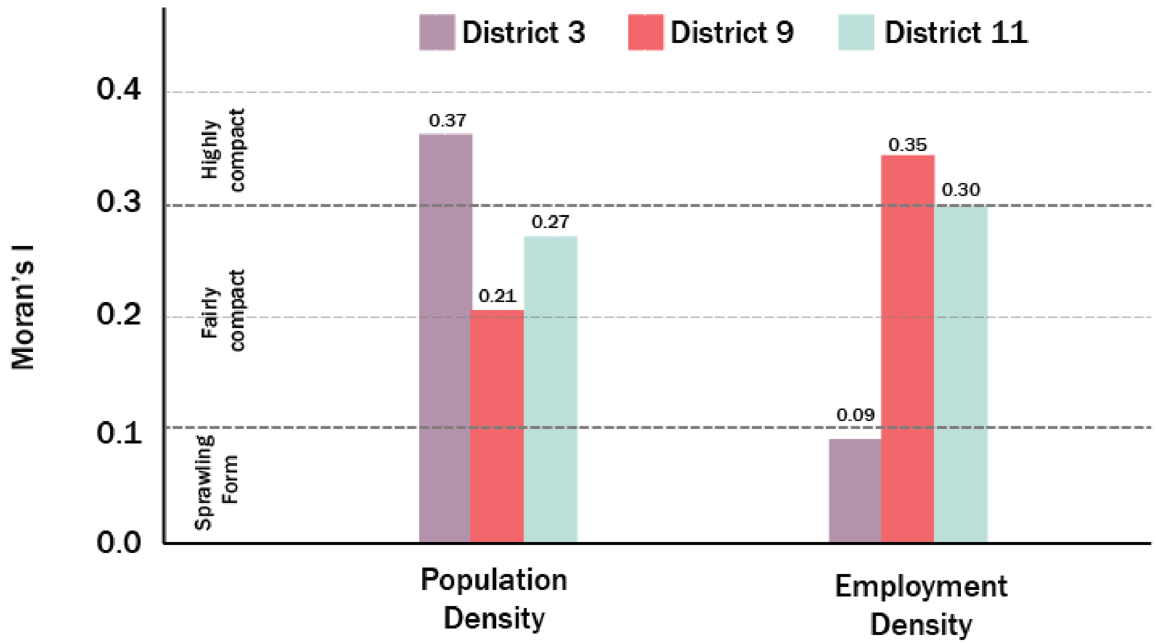


Figure 4.2 Interpretation of Moran's I for districts 3, 9 and 11

Results show that District 3 has the highest concentration of population densities, while the district's employment densities show a sprawling form, with Moran's I at 0.09. On the contrary, while districts 9 and 11 have a relatively compact concentration of population densities, they exhibit a highly compact concentration of employment densities.

4.1.2 Hot-Spot analysis

Hot-spot analysis (Getis-Ord Gi*) is a tool on ArcMap that identifies statistically significant spatial clusters of high values (hot-spots) and low values (cold-spots) using the Getis-Ord Gi* statistic. Hot spot analysis calculates the spatial clustering of the mapped features relative to features mapped close by. This test was conducted for population and employment density in districts 3, 9 and 11. The analyses returns a z-score where higher values reflect greater clustering, and low values denote no clustering. The Hot-spot analysis for population density and employment density for districts 3, 9 and 11 are presented in figures 4.3, 4.4, and 4.5, respectively.

In District 3, the high clusters of population and employment density are observed near the control group, i.e., along culverted stream sections, with low-level clustering of population and employment density near the treatment group.

In District 9, two distinct high clusters of population densities are found: one in the control area and one in the treatment area, whereas one high cluster of employment density spans across both the control and treatment group, while is there is also a low-level clustering of employment densities in the treatment group.

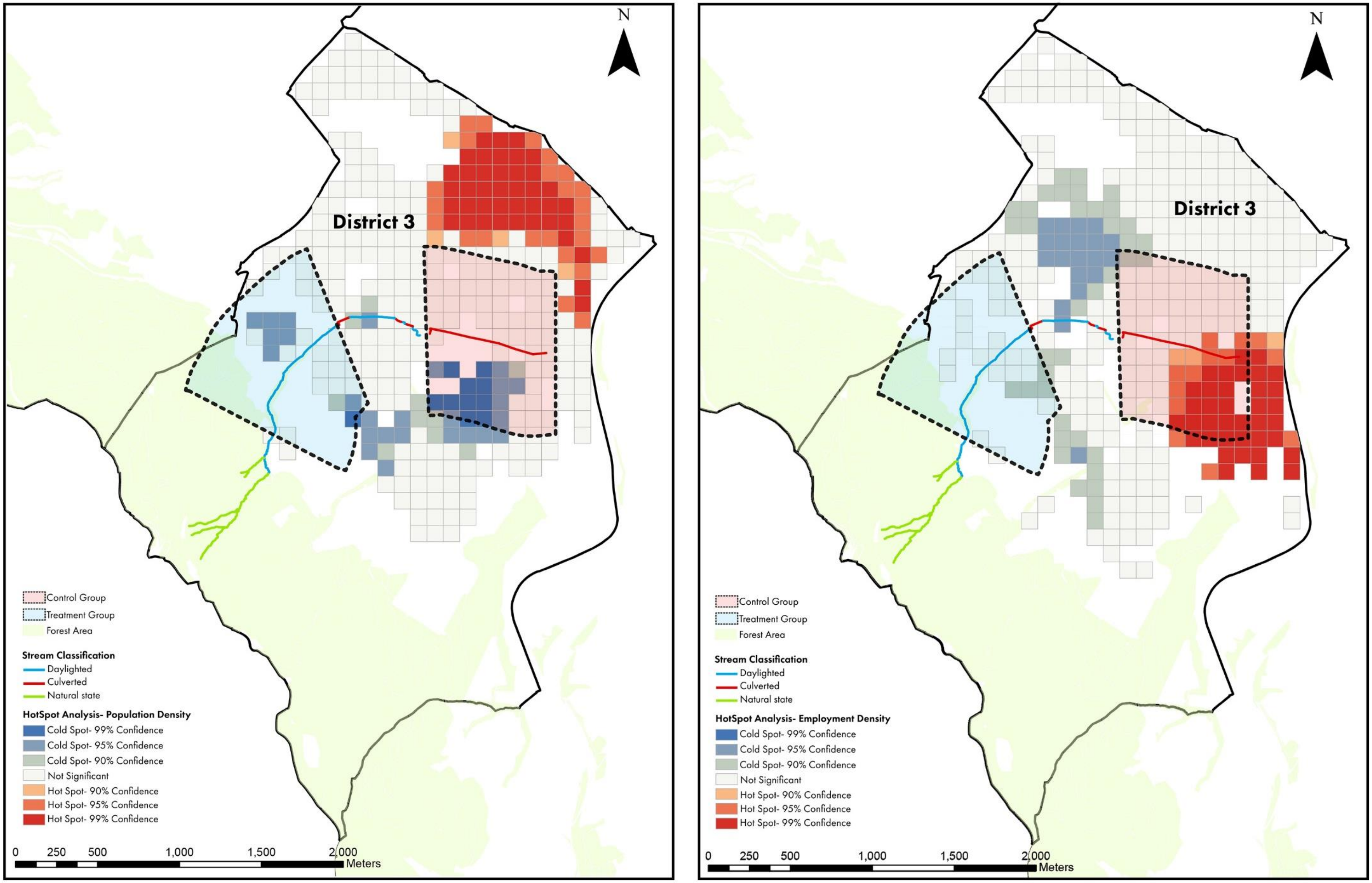


Figure 4.3 Hot Spot analysis (Getis-Ord Gi*) of population (left) and employment density (right) in District 3

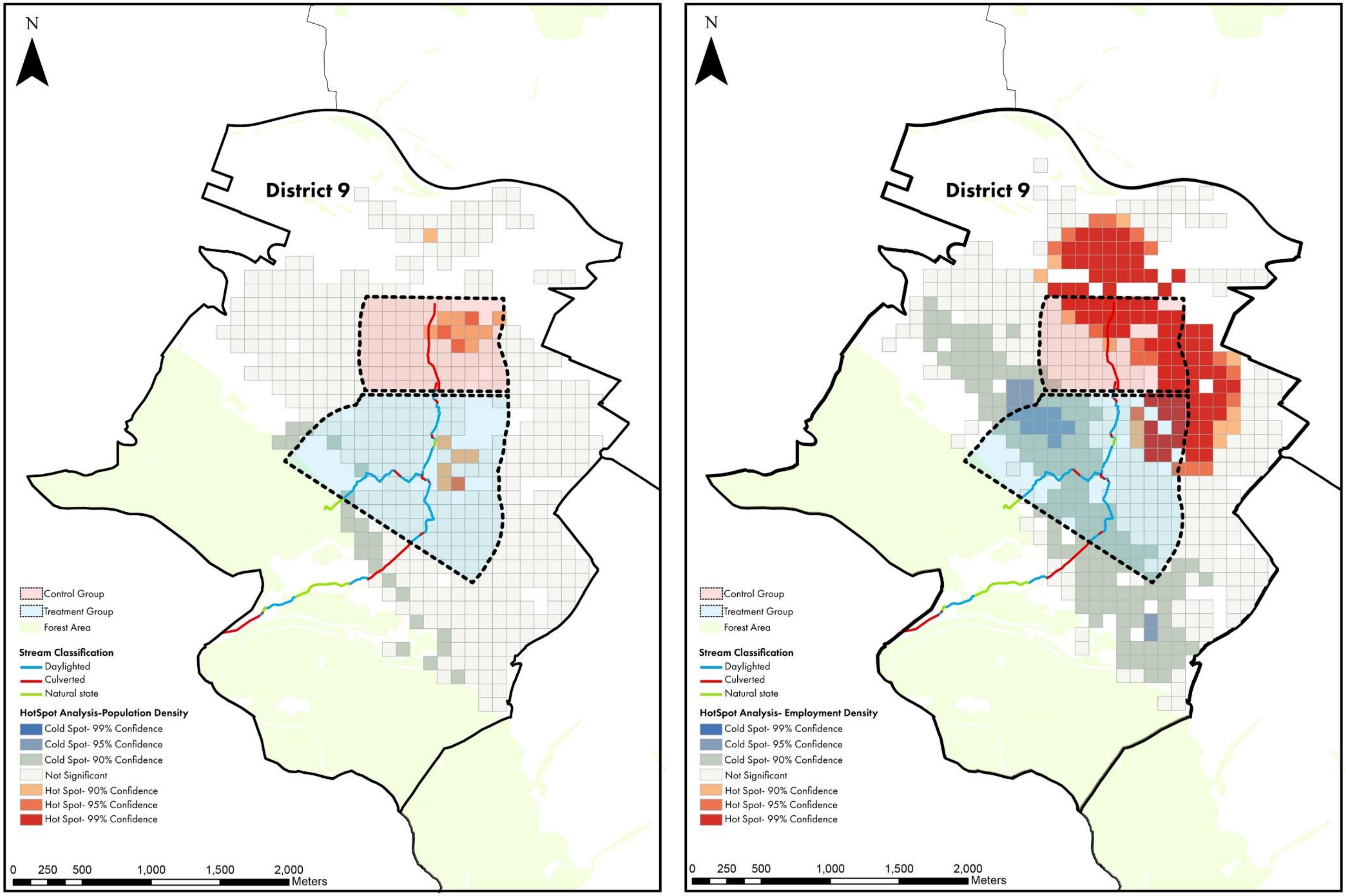
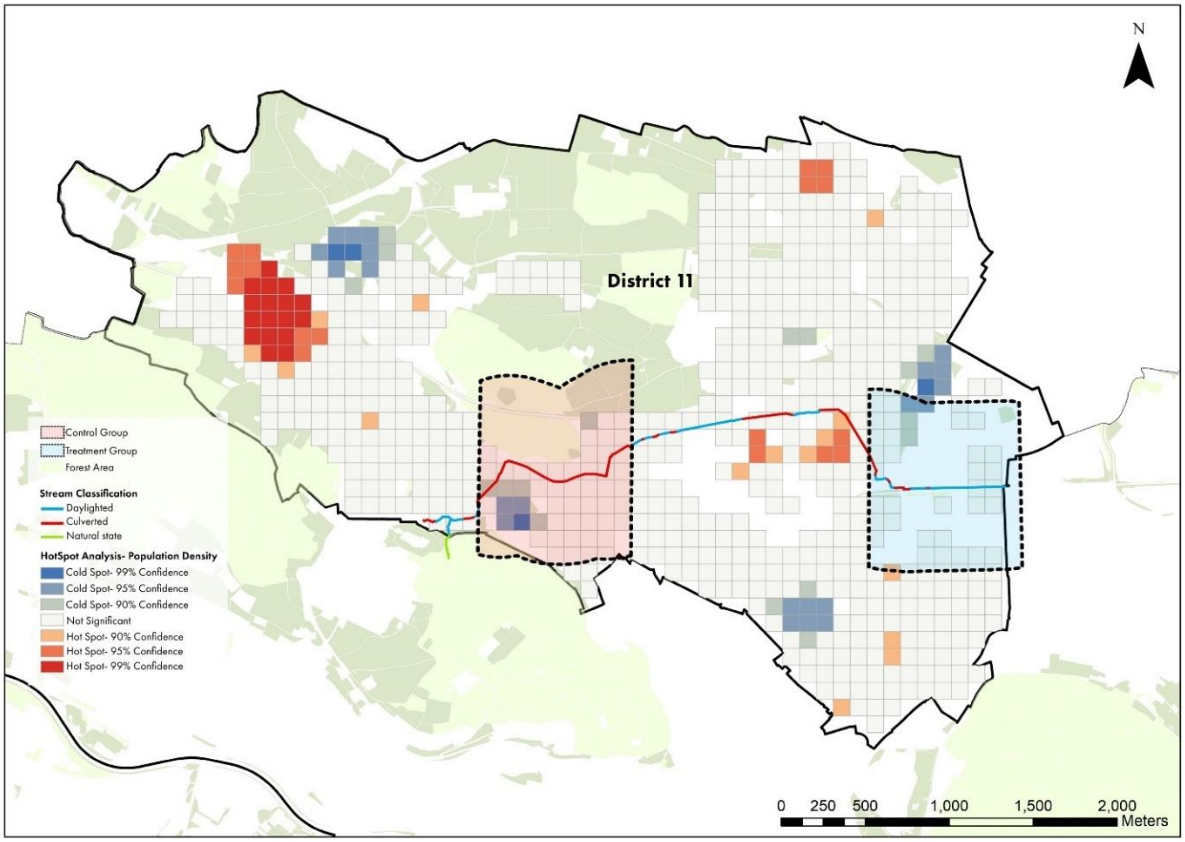


Figure 4.4 Hot Spot analysis (Getis-Ord Gi*) of population (left) and employment density (right) in District 9



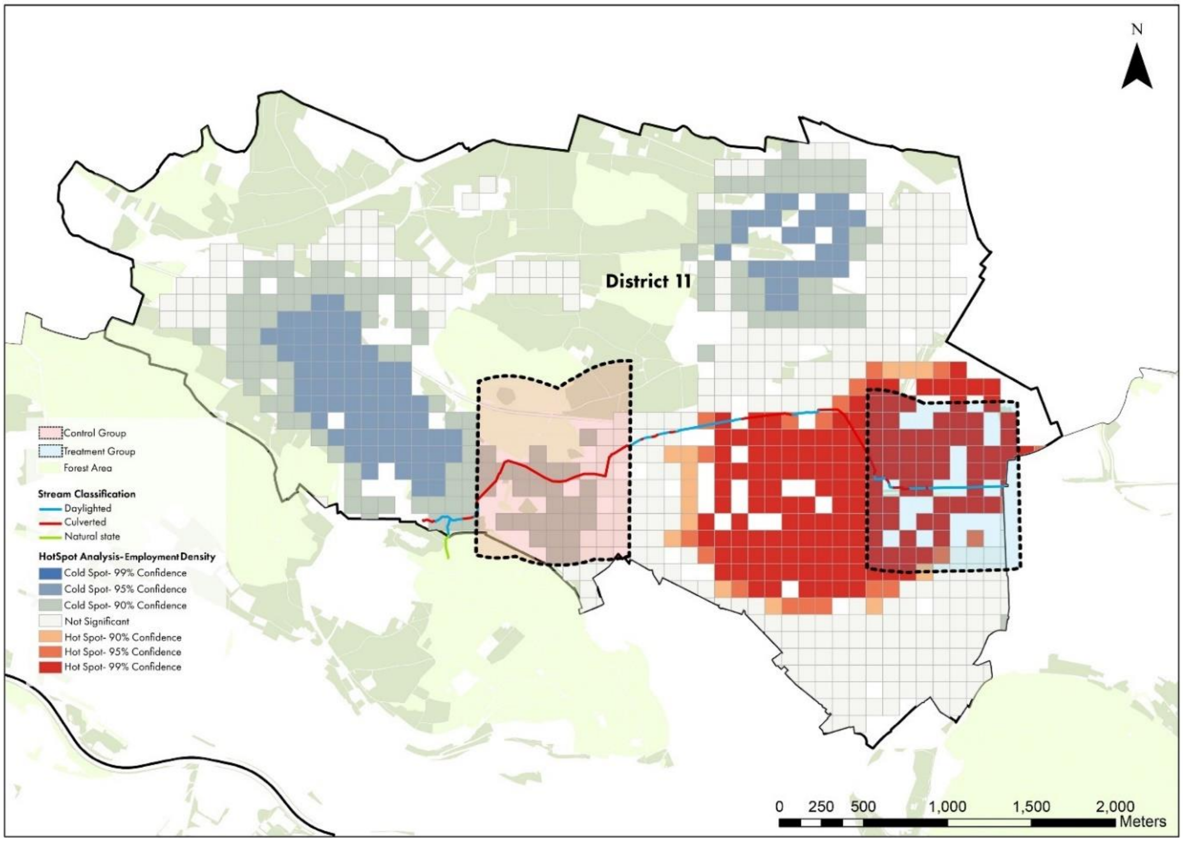


Figure 4.5 Hot Spot analysis (Getis-Ord Gi*) of population (top) and employment density (bottom) in District 11

In District 11, while there are no noticeable high clusters of population densities in either the control or treatment group, there is a distinct high cluster of employment density within the treatment group, spanning across the daylighted sections of the stream. In stark contrast, there are low clusters of employment density in the control group.

Table 4.4 Summary of Hot Spot Analysis (Getis-Ord Gi*) in districts 3, 9 and 11

District	**Population density**		**Employment density**	
	Control group	**Treatment group**	**Control group**	**Treatment group**
District 3	Low clusters	Low clusters	High clusters	Low & insignificant clusters
District 9	High clusters	High & insignificant clusters	High clusters	High & low clusters
District 11	Low & insignificant clusters	Low & insignificant clusters	Low clusters	High clusters

In summary, high clusters of employment density are found in the treatment groups in two of the three districts (i.e., districts 9 and 11), while the clustering of population density is relatively low in two of three districts (i.e., districts 3 and 9). Therefore, while there is some high level of clustering in employment density in the control and treatment groups, there is low-level clustering of population density in the treatment groups compared to the control groups.

4.1.3 Local scale analysis of density and building stock

This section compares the urban densities between the control and treatment groups to explore the relationship between stream daylighting and population and employment density. In addition to population and employment density, the number of households and construction activity is compared between the control and treatment groups.

4.1.3.1 Statistical test for significance

First, a Chi-square statistic test is carried out to determine a statistical difference in population and employment density between the control and treatment groups in districts 3, 9 and 11. The null hypothesis considered for this test is that there is no statistically significant difference between population density, employment density, number of households, and the nature of the treatment of the stream sections (i.e., culverted or daylighted). Table 4.5 summarizes the Chi-square values for the independent variables in districts 3, 9 and 11.

Table 4.5 Chi-square test of independence for independent variables

District	Variables	χ^2 value	p-value	Significance	Note
District 3	Population density	1.964	0.161	Not significant	The result is *not significant* at $p \leq 0.05$. Hence, the null hypothesis is accepted.
	Employment density	6.118	0.013	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.
	Number of	2.595	0.107	Not	The result is *not significant* at $p \leq 0.05$. Hence, the null

	households			significant	hypothesis is accepted.
District 9	Population density	10.315	0.006	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.
	Employment density	18.381	0.0001	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.
	Number of households	4.861	0.182	Not significant	The result is *not significant* at $p \leq 0.05$. Hence, the null hypothesis is accepted.
District 11	Population density	0.243	0.622	Not significant	The result is *not significant* at $p \leq 0.05$. Hence, the null hypothesis is accepted.
	Employment density	16.206	0.0003	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.
	Number of households	6.979	0.0305	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.

In District 3, results show that employment density is significant, i.e., the observed frequencies in employment densities are statistically different between the control and the treatment group. On the other hand, population density and the number of households are not significant, i.e., the observed frequencies between the control and treatment groups are fairly similar. Hence, in District 3, employment density and the treatment of stream sections are significant, whereas population density and the number of households are not significant between the culverted and daylighted sections of the stream. In District 9, the values for Chi-square test for population and employment density are statistically significant, whereas the number of households are not significant and are fairly similar. Similarly, in District 11, employment density and the number of households are statistically significant between the culverted and daylighted sections of the stream, while the population density is not significant.

4.1.3.2 District 3

As mentioned in the previous section, the frequencies in densities and the number of households are compared between the control group and treatment group in each of the three districts. Results from the Chi-square test for District 3 showed that the population densities and the number of households do not differ significantly between the control group and treatment group, whereas the employment densities differ significantly between the two groups. Figures 4.6 and 4.7 present the population and employment density frequencies between the control and treatment groups, respectively.

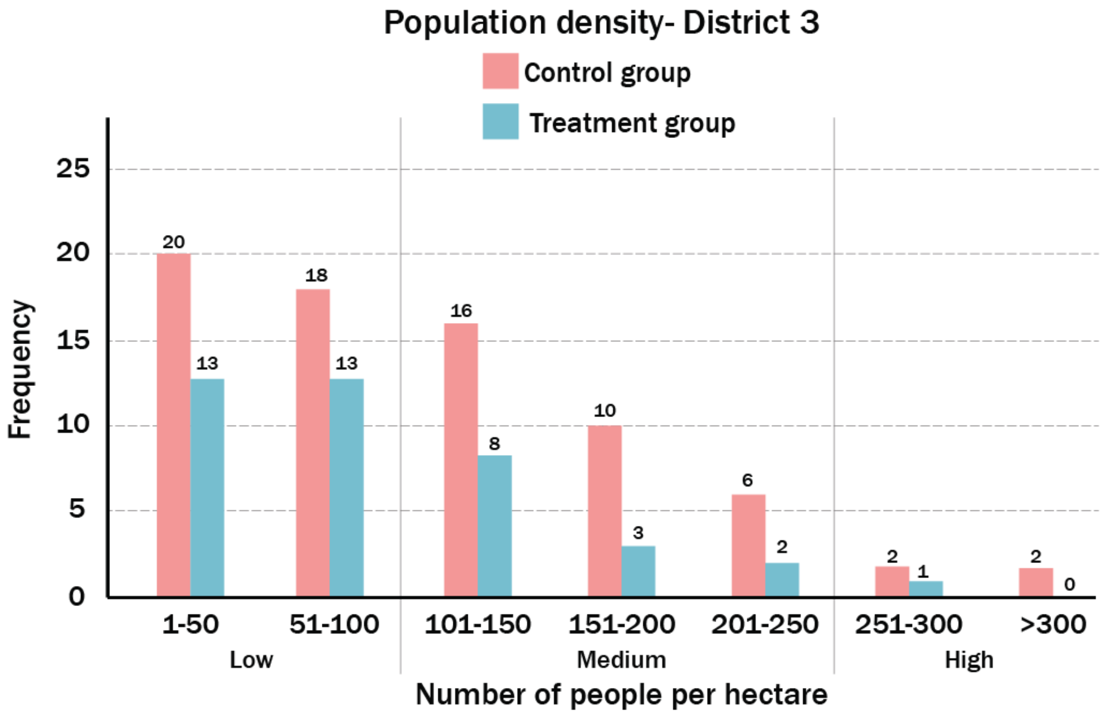


Figure 4.6 Frequencies of population density in District 3 between culverted stream buffer (Control group) and daylighted stream buffer (Treatment group)

The mean population density in District 3 is 136 persons per hectare. In comparison, the mean population densities within the control and treatment group are 108 persons per hectare and 90 persons per hectare, respectively. This further corroborates the results from the Chi-square test that the population densities are fairly similar between the culverted stream area and the daylighted stream area. Additionally, low to medium population densities are observed in the control group (51% lie between 1-100 persons per hectare, 43% lie between 101-250 persons per hectare) and in the treatment group (65% lie between 1-100 persons per hectare, 32% lie between 101-250 persons per hectare). The population densities observed in the treatment group are comparatively lesser than those observed in the control group. This might be due to the geographic location of the daylighted section of the stream, i.e., the daylighted section of the stream is in the periphery of District 3, closer to the forest and meadow area. On the contrary, results from Moran's I for population density within the district showed that the densities are highly compact. This points to the potential of sustainably and ecologically growing the densities in close proximity to the daylighted section of the stream without outgrowing the developments in forest areas, which in turn can curtail sprawl.

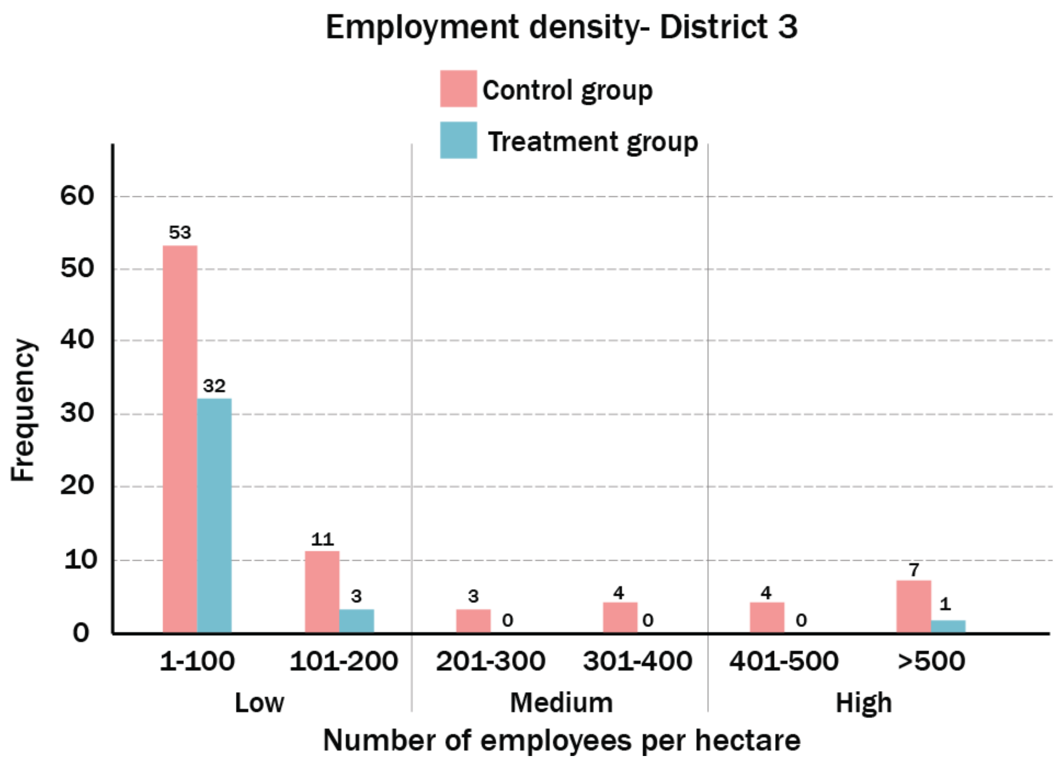
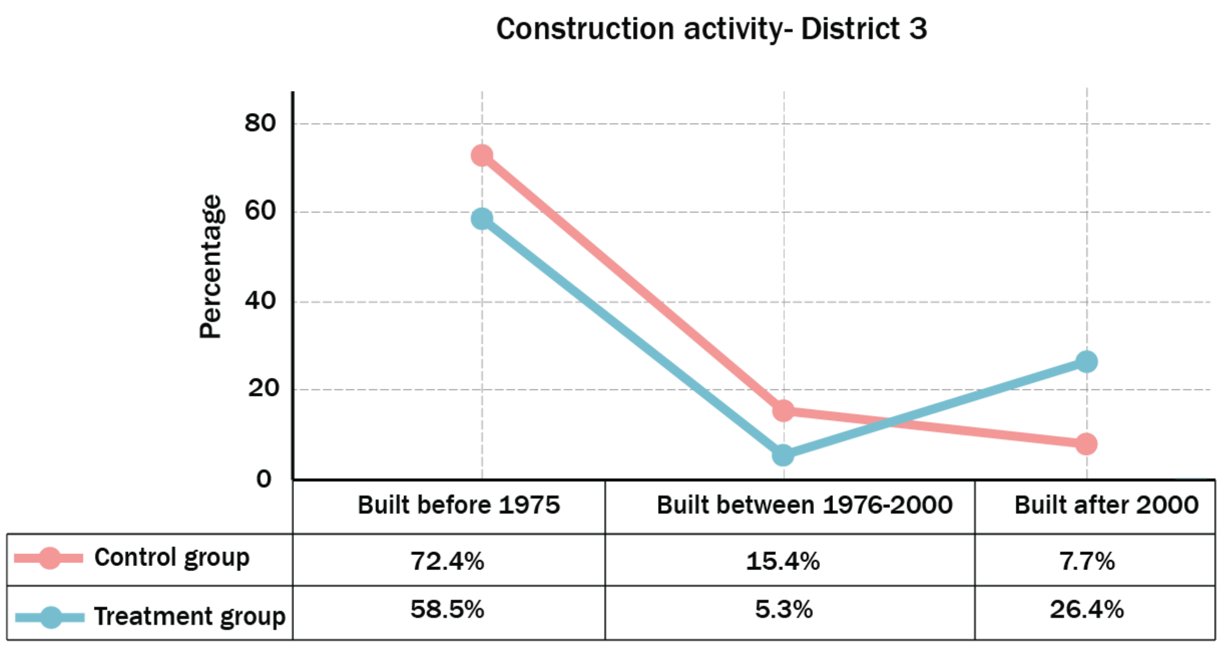


Figure 4.7 Frequencies of employment density in District 3 between culverted stream buffer area (Control group) and daylighted stream buffer area (Treatment group)

The mean employment density within the district is 109 employees per hectare. Similar to population density, the mean employment density within the control group is much higher at 176 employees per hectare, while the mean employment density within the treatment group is 105 employees per hectare.



	Built before 1975	Built between 1976-2000	Built after 2000
Control group	72.4%	15.4%	7.7%
Treatment group	58.5%	5.3%	26.4%

Figure 4.8 Comparison of construction activity in District 3 between culverted stream area (control group) and daylighted stream area (treatment group)

In District 3, buildings within the control group are relatively older, with over 72% built before 1976, whereas the percentage of buildings built before 1975 within the treatment group is 58%. Construction activity within both the control and treatment group dropped between the years 1976-2000. A sharp increase in construction activity is observed after 2000 within the treatment group from 5.3% between the years 1976-2000 to 26.4% built after the year 2000. This corresponds to the year the stream Friesenbergbach was daylighted, i.e., 1991.

4.1.3.3 District 9

In District 9, the results from Chi-square test show that population and employment densities are statistically significant between the culverted and daylighted sections of the stream. Figures 4.9 and 4.10 present the frequencies in population and employment density, respectively.

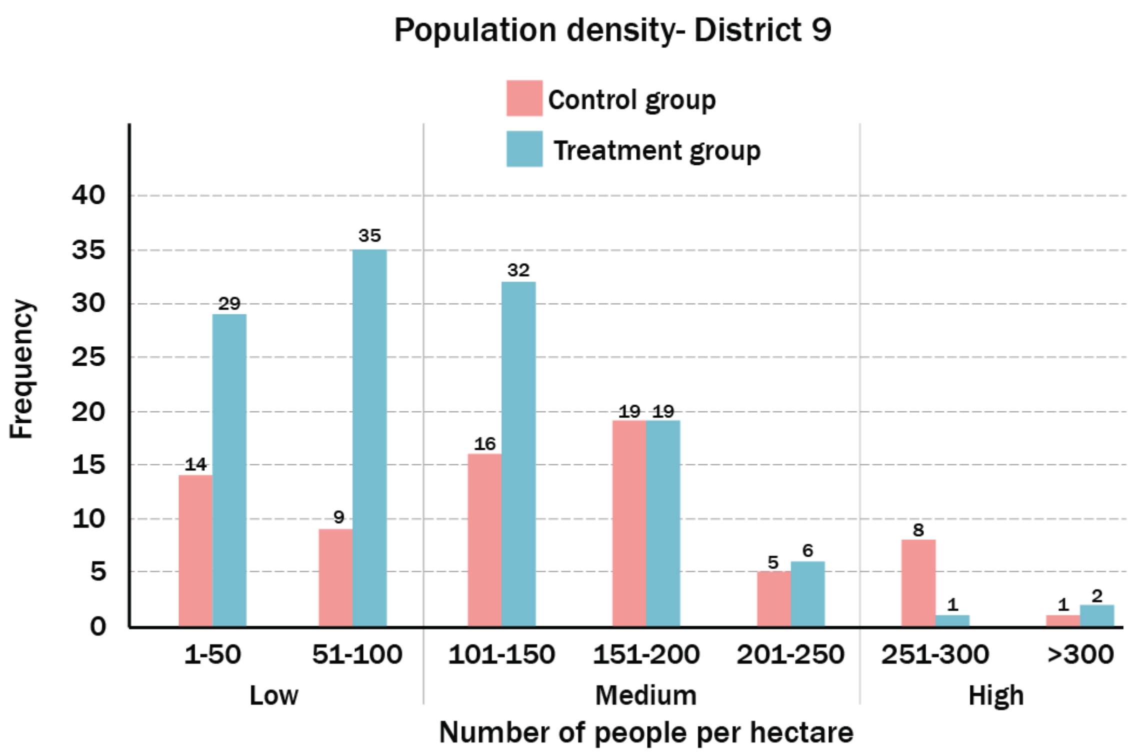


Figure 4.9 Frequencies of population density in District 9 between culverted stream buffer area (Control group) and daylighted stream buffer area (Treatment group)

The mean population density in District 9 is 112 persons per hectare. The mean population density within the control and treatment groups is 140 persons per hectare and 110 persons per hectare, respectively. Similar to District 3, the mean population density within the control group is higher than the mean population density within the treatment group. Both the control and the treatment group support low – medium densities, with over 87% in the control group between 1-250 persons per hectare, and 97% within the treatment group lie in the same range.

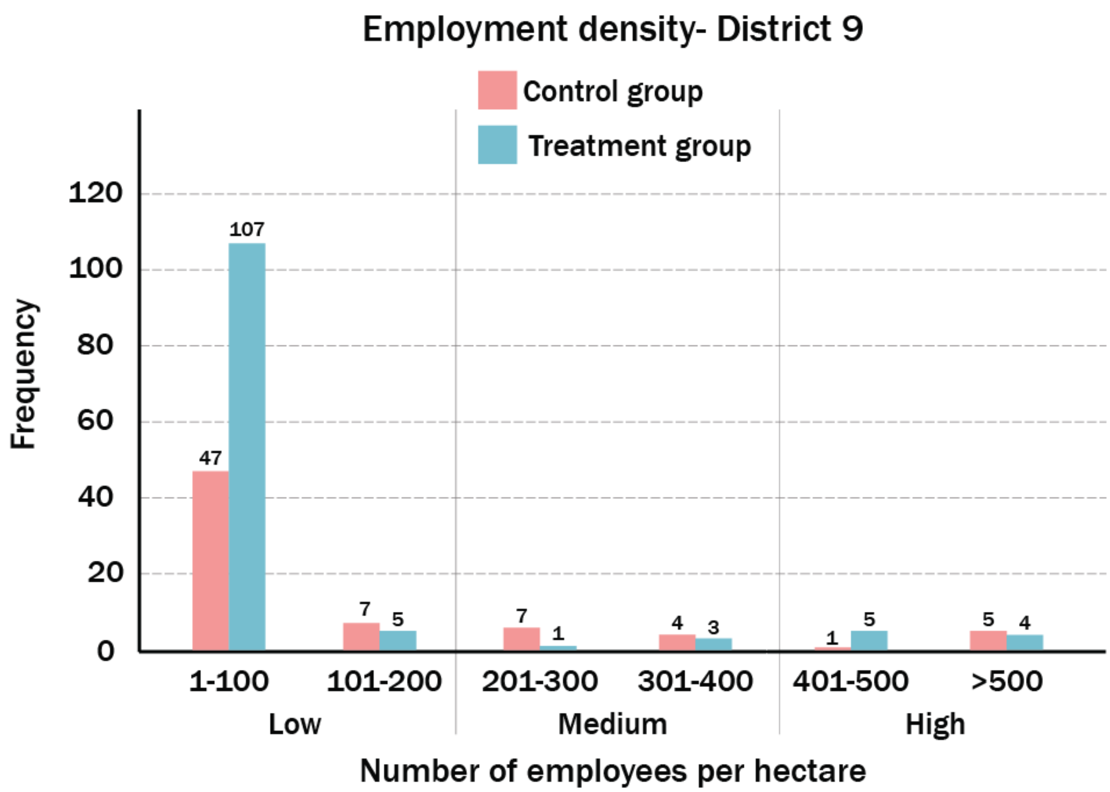
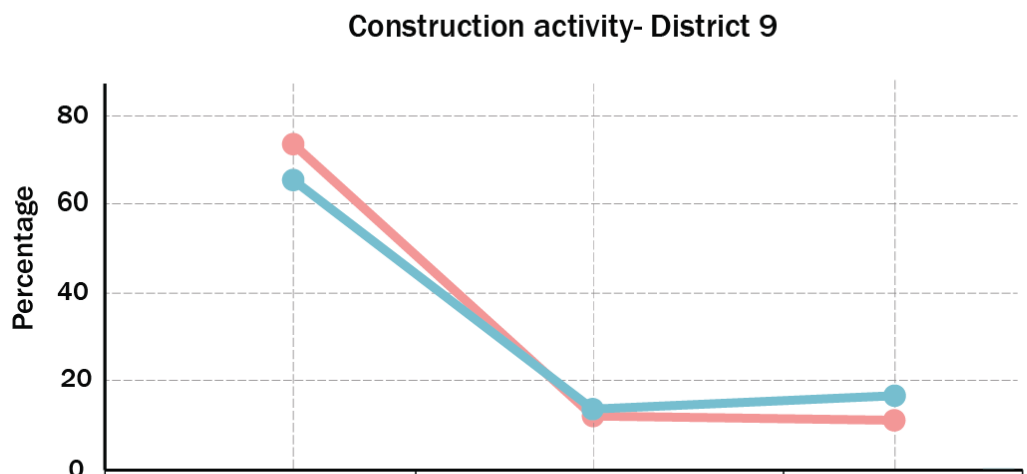


Figure 4.10 Frequencies of employment density in District 9 between culverted stream buffer area (Control group) and daylighted stream buffer area (Treatment group)

The mean employment density in District 9 is 96 employees per hectare. Similar to population density, the observed mean employment density within the control group is higher than the treatment group at 137 employees per hectare and 74 employees per hectare, respectively.



	Built before 1975	Built between 1976-2000	Built after 2000
Control group	73.1%	12.5%	11.3%
Treatment group	65%	13%	16.4%

Figure 4.11 Comparison of construction activity in District 9 between culverted stream area (control group) and daylighted stream area (treatment group)

In District 9, within the control group, 73% of the buildings were built before 1975, while 65% of the buildings within the treatment group were built before 1975. A drop in construction activity is noted between the years 1976- 2000 within the control and the treatment group, with an increase in construction activity after the year 2000 within the treatment group. This corresponds to the year the stream Albeisreider Dorfbach was daylighted, i.e., 1991.

4.1.3.4 District 11

In District 11, employment density is statistically significant between the control and treatment groups, whereas there is no statistical significance in population densities between the two groups. Figure 4.12 and 4.13 shows the observed frequencies of population and employment density between the control and treatment groups, respectively.

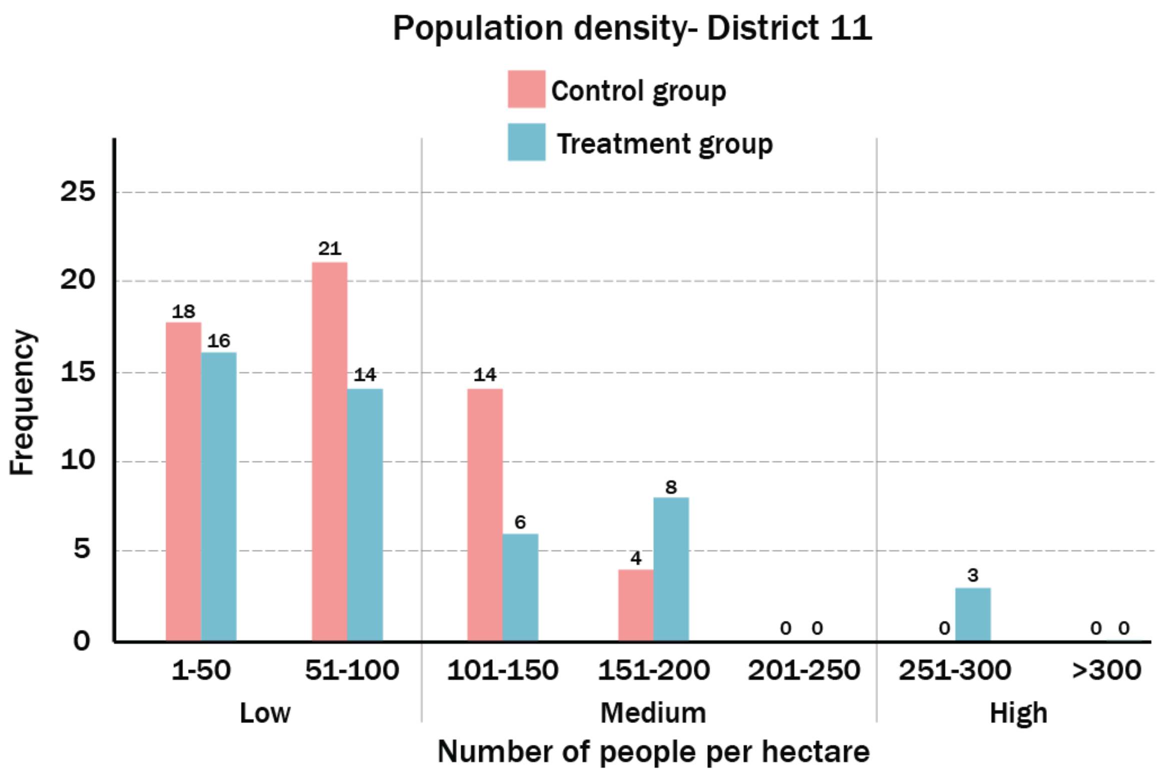


Figure 4.12 Frequencies of population density in District 11 between culverted stream buffer area (Control group) and daylighted stream buffer area (Treatment group)

The mean population density in District 11 is 108 persons per hectare. The observed mean population density in the control and treatment groups within this district is lower than the districts mean at 75 persons per hectare and 92 persons per hectare, respectively. While the results from Chi-square test for population density turned out to be insignificant, the mean population density in the treatment group is higher than the mean in the control group. Similar to districts 3 and 9, in District 11, both the groups support low to medium densities while the treatment group has 6% of the cells with a high density of 250- 350 persons per hectare.

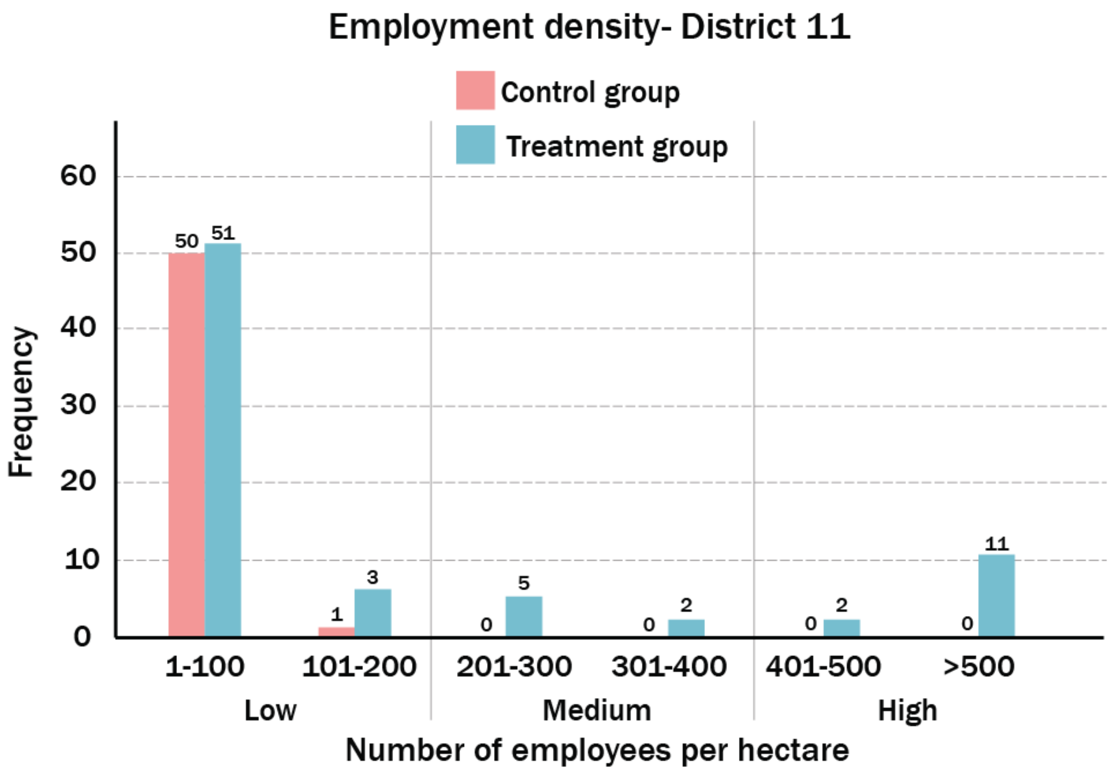
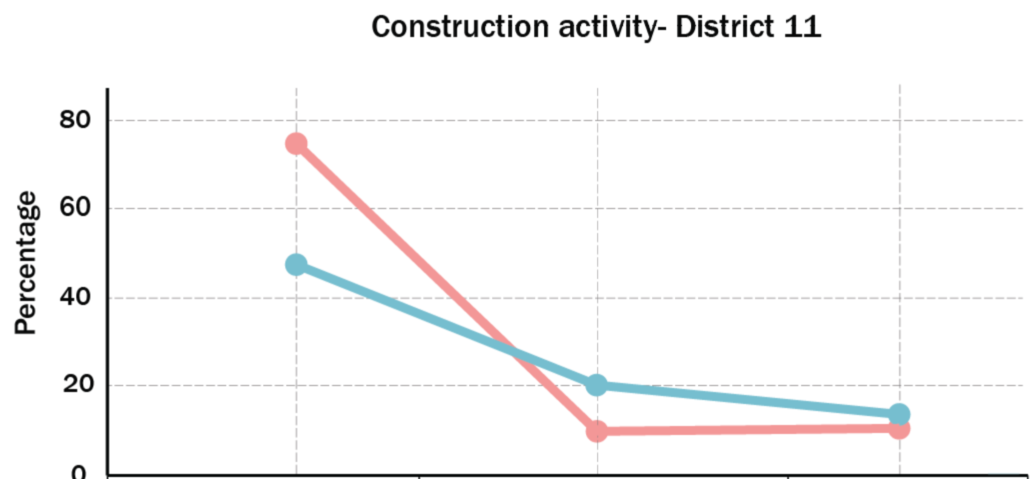


Figure 4.13 Frequencies of employment density in District 11 between culverted stream buffer area (Control group) and daylighted stream buffer area (Treatment group)

The mean employment density in District 11 is the lowest compared to districts 3 and 9 at 70 employees per hectare. However, the treatment group within the district has the highest mean employment density at 203 employees per hectare, while the control group's mean employment density is the lowest at 18 employees per hectare.



	Built before 1975	Built between 1976-2000	Built after 2000
Control group	74.8%	9.8%	10.5%
Treatment group	47.3%	20.2%	13.7%

Figure 4.14 Comparison of construction activity in District 11 between culverted stream area (control group) and daylighted stream area (treatment group)

A majority of the buildings within the control group (75%) in District 11 were built before 1975, while only 47% of the buildings within the treatment group were built before 1975. Although construction activity dropped between 1976-2000 in both the control and treatment groups, a higher percentage of buildings (20% compared to 9.8% in the control group) were built in the treatment group during these years. Unlike districts 3 and 9, a drop in construction activity is observed after 2000 in the treatment group, which was when the stream Binzmühlebach was daylighted, i.e., 2000.

4.2 Diversity analysis

For diversity analysis, two variables are used: land use mix and mixture of lot sizes. Land use mix is calculated using a modified version of Simpson's Diversity Index, whereas the mixture of lot sizes is calculated using the power-law function.

4.2.1 Land use mix

The claim that fine urban grain plays a vital role in land use mix is perhaps the most significant in literature. Land use profiles are one of the most common and basic forms of land use analysis. Land use zones in the city of Zürich are regulated in their land use plans. In this study, seven land use zones, namely, core zone, conservation zone, industrial and commercial zone, zone for public buildings, residential zone, and free and recreation zone, are considered at the lot level, and their diversity is calculated using Simpson's diversity index.

The land use zones are obtained as generalized land use at the lot level. Data is then processed by eliminating roadways, railways, waters, and agricultural areas. The land uses are generalized at the lot level and do not account for the different uses within the building. Table 4.12 shows the percentage of land use zones, and Figures 4.15 and 4.16 present the maps of land use zones in districts 3, 9 and 11.

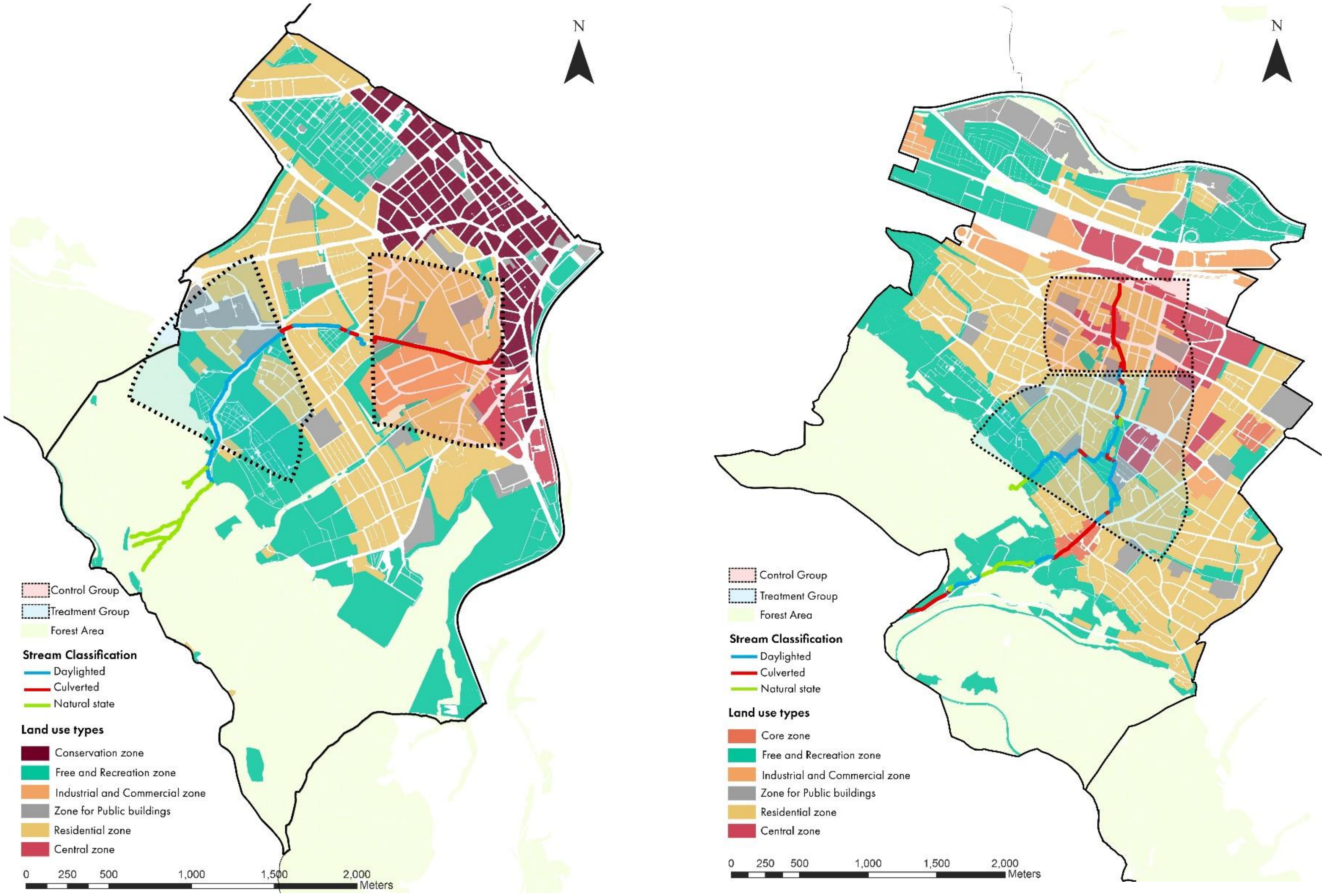


Figure 4.15 Land use zones in District 3 (left) and District 9 (right)

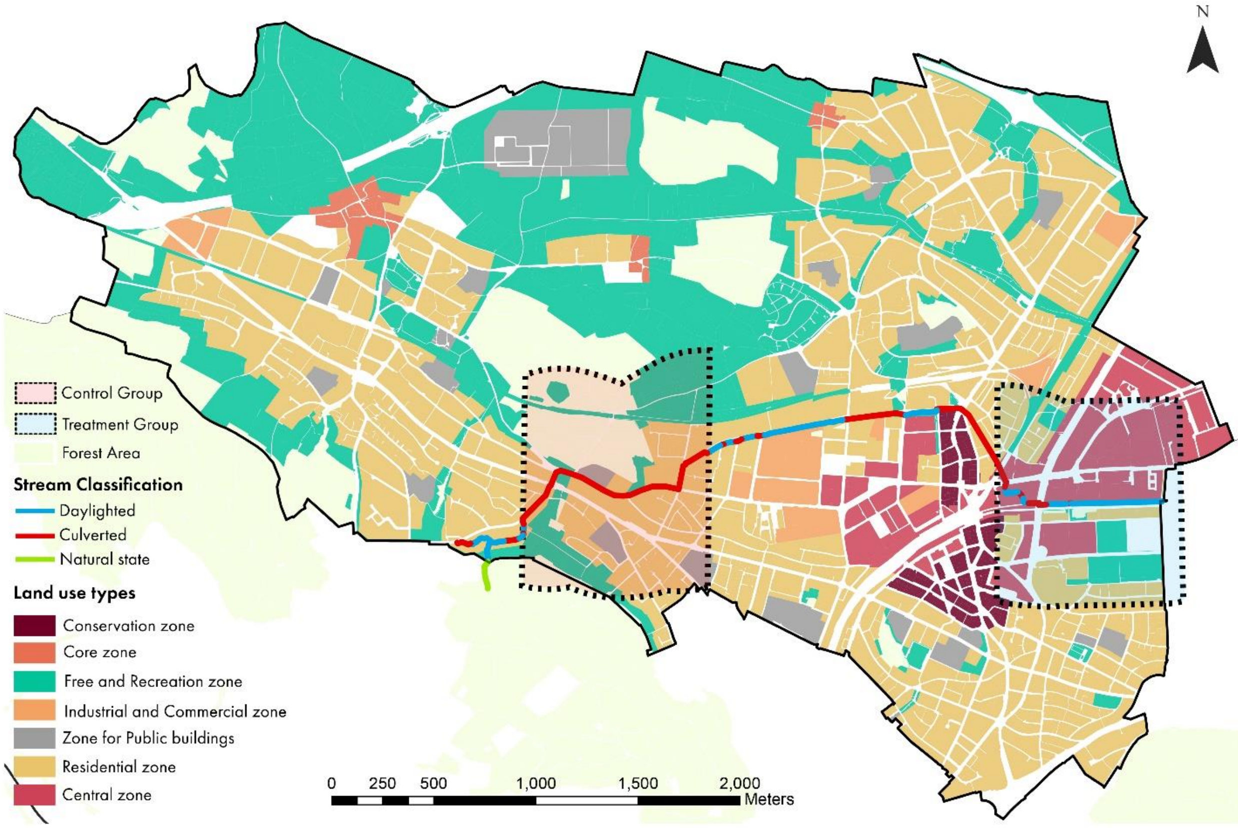


Figure 4.16 Land use zones in District 11.

The table below shows that the primary land use zone in districts 3, 9 and 11 is residential, followed by *free and recreation zone*, i.e., indoor and outdoor public spaces meant for recreational facilities. *Core zones* are zones meant for intense developments within the districts. In total, only 1% in districts 9 and 11 is designated as a core zone, while there is no core zone in District 3.

Table 4.6 Percentage of land uses in the study area.

Land use category	District 3 (%)	District 9 (%)	District 11 (%)
Central zone	3	8	7
Conservation zones	11	0	2
Core zone	0	1	1
Free and Recreation zone	36	31	39
Industrial and Commercial zone	3	9	3
Zone for Public Buildings	8	9	5
Residential zone	38	42	44

A modified version of Simpson's Diversity Index is used to examine the mix of land uses in districts 3, 9 and 11. The Diversity Index (D) can be expressed as:

$$D = \frac{N(N-1)}{\sum_i n_i\,(n_i - 1)}$$

Where, N= total area of all land use zones in the districts; and n_i= area of a land use zone in the *'i'th* category. This specific formulation is a reciprocal index, allowing for a more intuitive interpretation of values where 1 represents a community with only one species or category. The higher the value, the greater the diversity, and the maximum value is the number of categories in the sample, which is 7 in this case. The Simpson's Diversity Index for districts 3, 9 and 11 are 3.34, 3.44, and 2.86, respectively. The results show that land use zones are not as diverse in the districts and are clustered and not mixed. However, it is evident that the districts have almost equal percentages of residential zones and free and recreation zones.

4.2.1.1 Diversity of land uses at the local scale

This section looks at the diversity of land use zones between the control and treatment groups to explore a possible correlation between stream daylighting and diversity. First, the percentages of land uses are compared between the control group and treatment groups followed by the calculation of Simpson's Diversity Index between the two groups.

Table 4.7 Distribution of land use zones in the control group and treatment group

Land use type	District 3 (%)		District 9 (%)		District 11 (%)	
	Control group	Treatment group	Control group	Treatment group	Control group	Treatment group
Central zone	5.9	0	23.8	5.3	0	54.4
Conservation zones	2.0	0	0.0	0	0	2.0
Core Zone	0	0	0	0	0	0
Free and Recreation zone	9.2	49.8	2.6	19.6	36.8	13.1
Industrial and Commercial	20.6	0	0.5	15.5	0	0
Public Buildings	7.1	18.7	13.7	7.1	7.1	0
Residential	55.2	31.5	59.4	52.6	56.1	30.5

The table presented above shows the distribution of land use zones between the control group and treatment group in districts 3, 9 and 11. Results show that within the treatment groups in districts 3 and 9, free and recreation zones are higher at 50% and 20%, respectively, compared to 9% and 3% in the control group. However, in the treatment group in District 11, the percentage of free and recreation zone is less than in the control group at 13% and 37%, respectively. This is because the control group is close to the pasture and meadow area, which is a free and recreation zone according to the land use plans in Zürich.

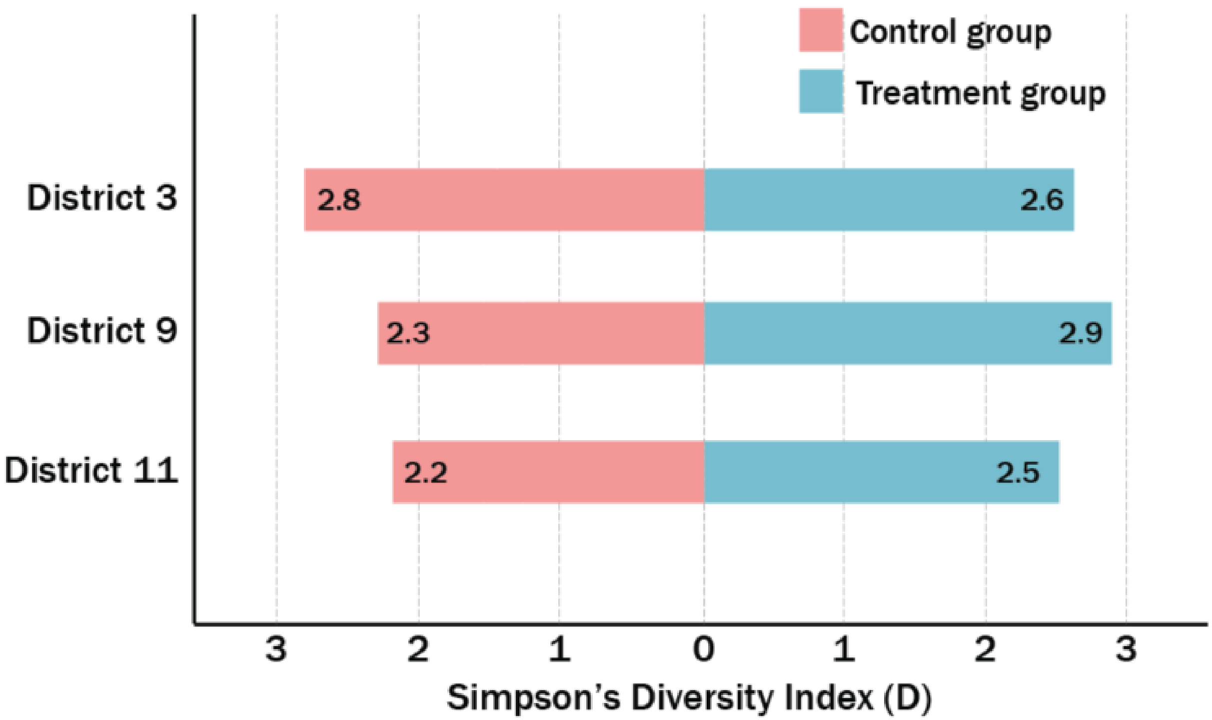


Figure 4.17 Simpson's Diversity Index (D) for land use zones in the control group and treatment group in Districts 3, 9 and 11.

Further, Simpson's Diversity Index is calculated to compare the mix of land uses between the control group and the treatment group. The results from Simpson's Diversity Index is presented in Figure 4.17. In district 3, the Diversity Index in the control group is higher at 2.8 compared to the treatment group at 2.6. However, in Districts 9 and 11, the Diversity Index in the treatment group is higher at 2.9 and 2.5, respectively, compared to the control group at 2.3 and 2.2.

In summary, land uses are relatively diverse in the control and treatment groups. However, the percentage of free and recreation zone in the treatment groups is higher than in the control groups. Similarly, results from the Simpson's Diversity Index show that land use zones within the treatment groups are more diverse than their respective control groups.

4.2.2 Power law distribution of lot sizes

A Chi-Square test is first carried out to check for statistical significance between the lot sizes in the control and treatment groups within districts 3, 9, and 11. The null hypothesis considered for this test is that there is no statistical significance between lot sizes and the treatment of stream sections, i.e., daylighted or culverted. In districts 3 and 11, Chi-square value is significant at $p \leq 0.05$, i.e., the lot sizes differ significantly between the control group and the treatment group. However, in District 9, the Chi-square value is not significant, and hence, the lot sizes do not differ significantly between the control group and treatment groups. Table 4.8 summarizes the values for Chi-square for districts 3, 9 and 11.

Table 4.8 Chi-square test of independence for lot sizes

District	Variable	χ^2 value	p-value	Significance	Note
District 3	Lot sizes	28.194	<0.0001	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.
District 9	Lot sizes	3.804	0.433	Not significant	The result is *not significant* at $p \leq 0.05$. Hence, the null hypothesis is accepted.
District 11	Lot sizes	59.533	<0.0001	Statistically significant	The result is *significant* at $p \leq 0.05$. Hence, the null hypothesis is rejected.

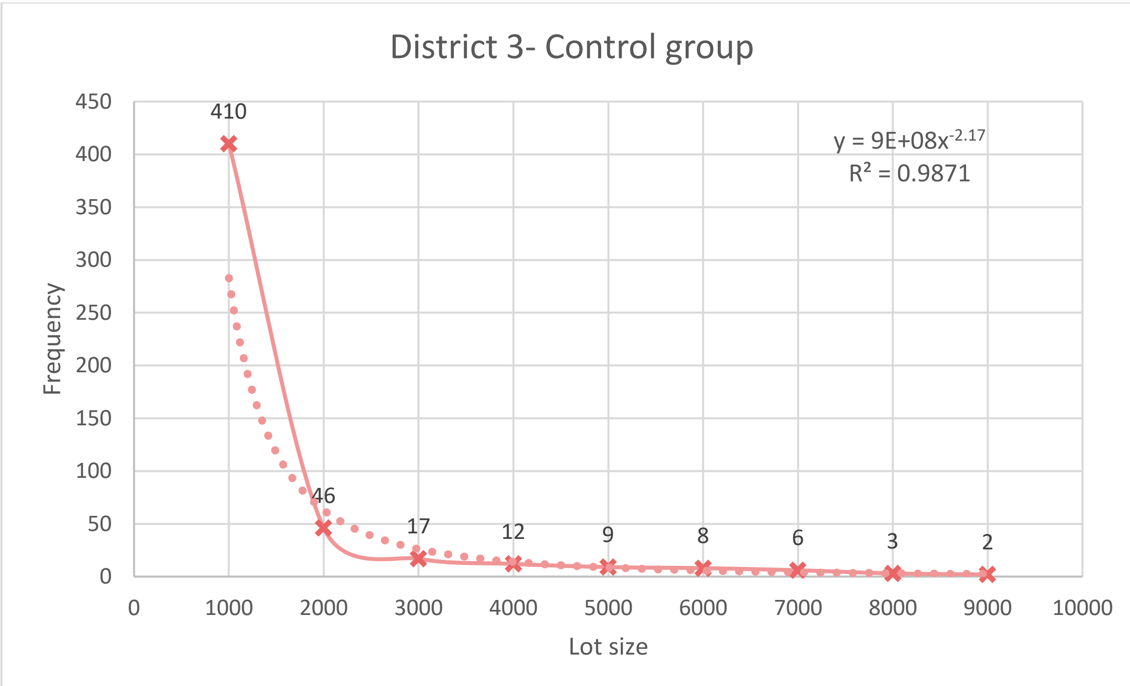
To determine if lot sizes follow power-law function, the lot sizes are plotted on the x-axis against their respective frequencies on the y-axis for the control and treatment groups. Then, the slope of the curve is derived to explore the power-law relation. The aim behind this analyses is the notion that smaller lot sizes are more manipulable in comparison to larger lot sizes and a mixture of lot sizes that follow power-law distribution are resilient to change (Tuura, 2014).

The bin intervals considered for the control and treatment groups is 1000 m^2, and lots smaller than 100 m^2 are considered outliers and are omitted from this analysis. Table 4.9 outlines the frequency of lot sizes between the control and treatment groups.

Table 4.9 Distribution of lot sizes between the control group and the treatment group in districts 3, 9 and 11

Frequency of lot sizes (m^2)	District 3		District 9		District 11	
	Control group	Treatment group	Control group	Treatment group	Control group	Treatment group
100-1000	410	45	297	302	394	190
1001-2000	46	8	81	69	42	28
2001-3000	17	5	20	20	12	26
3001-4000	12	4	15	12	4	12
4001-5000	9	1	5	5	1	8
5001-6000	8	3	3	2	1	3
6001-7000	6	3	4	3	1	4
7001-8000	3	1	-	-	2	6
8001-9000	2	4	-	-	4	4
9001-10000	-	-	-	-	1	1

A graph is plotted with the x-axis representing the scale size variable provided in the bins for lot sizes and the y-axis representing the frequency of lots in each bin. Figures 4.18, 4.19 and 4.20 present the scatter plots of the frequency of lot sizes in the control and treatment groups for each for the three districts. A power trendline is drawn based on the equation $y=ax^b$, where a is a constant b is the scaling exponent. The R^2 value is the measure of the proportion of variation between the variables.



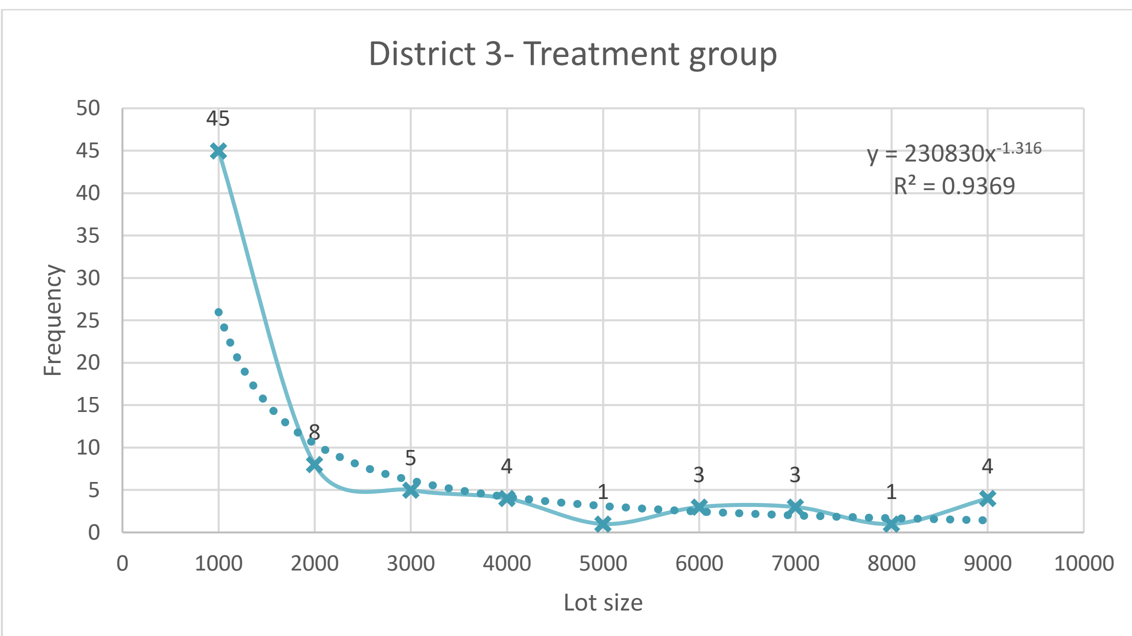
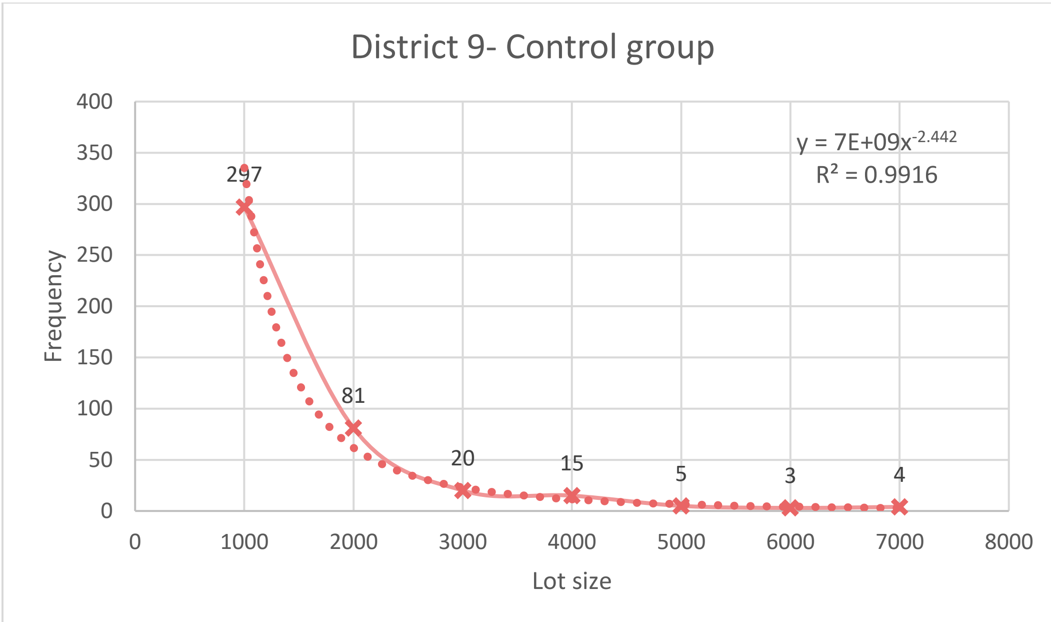


Figure 4.18 Power-law curve for lot sizes in District 3 for the control group (above) and the treatment group (below), where the dotted lines represent the trendline of the power curve.



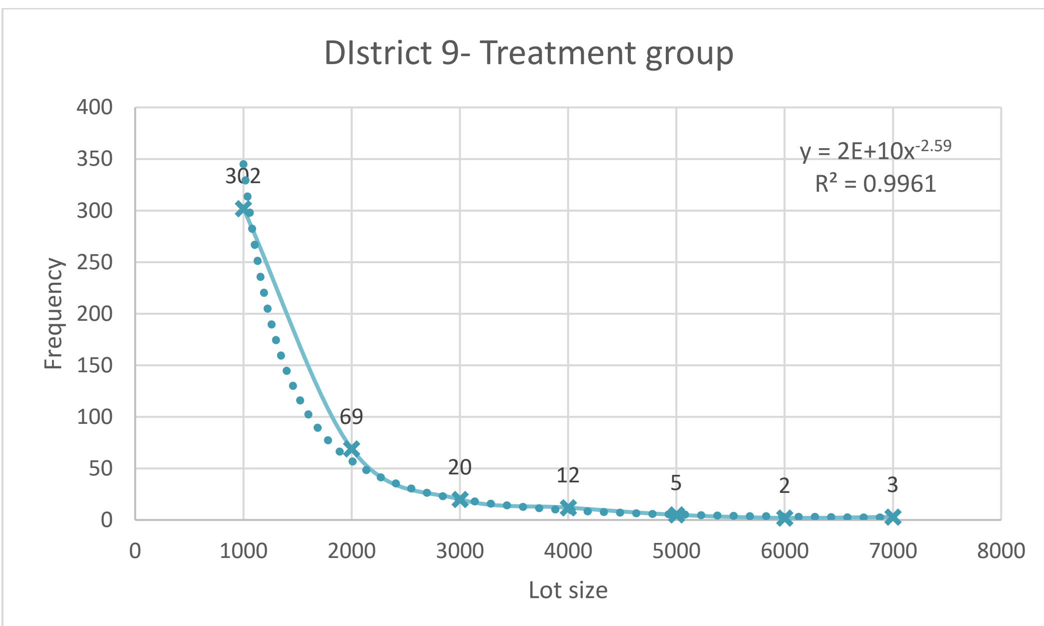


Figure 4.19 Power-law curve for lot sizes in District 9 for the control group (above) and the treatment group (below), where the dotted lines represent the trendline of the power curve.

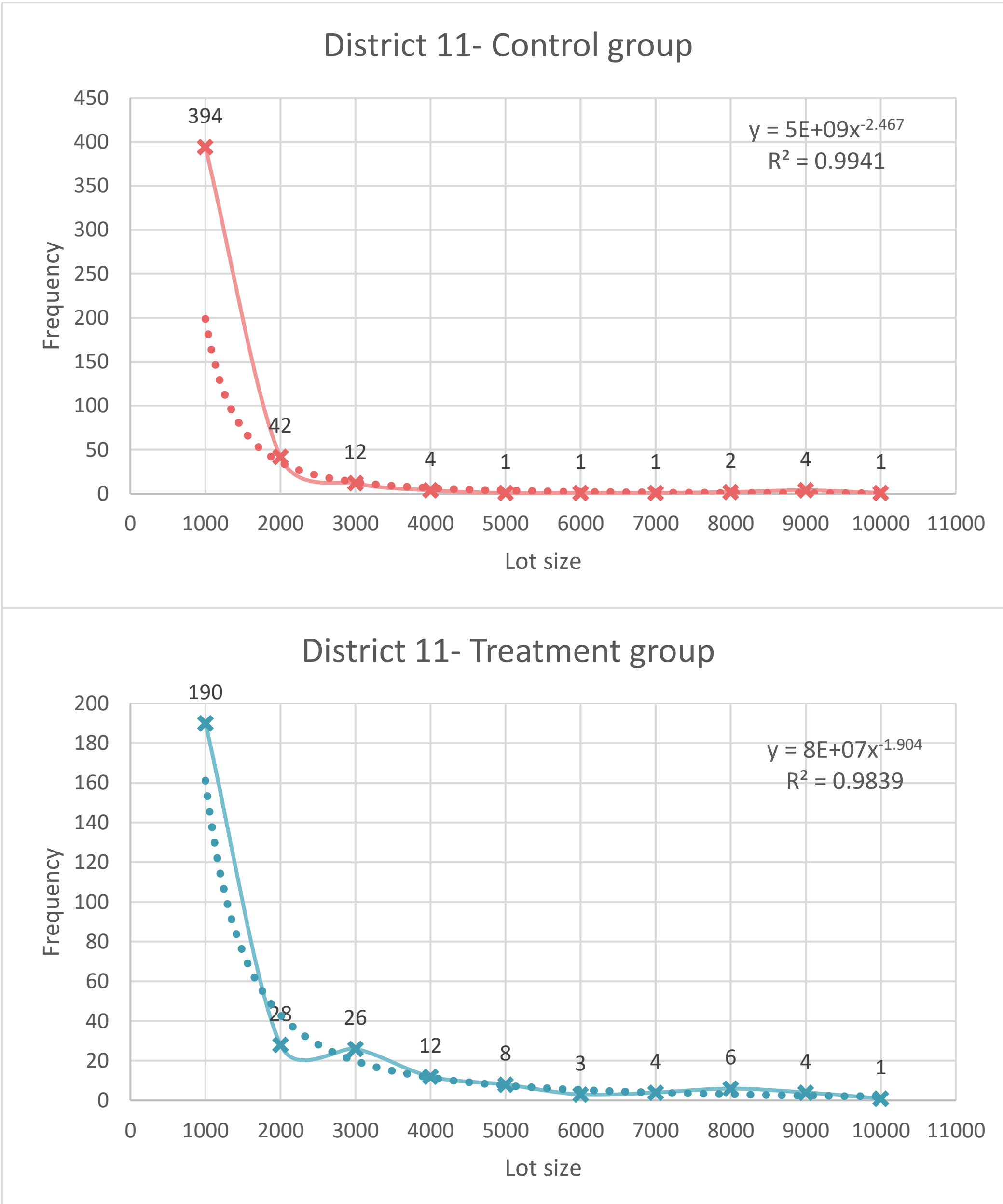


Figure 4.20 Power-law curve for lot sizes in District 11 for the control group (above) and the treatment group (below), where the dotted lines represent the trendline of the power curve.

The graphs show that all lot sizes within the control and treatment groups in all three districts follow power-law function with R^2 value ranging between 0.93 and 0.99, meaning that the observed values match the power curve. The lot sizes here represent the fractal property that all fractals follow a power-law relation (Jahanmiri, 2015). Hence, there is no significant difference in the mix of lot sizes between the control and treatment groups for the three districts.

4.3 Open Spaces

The provision of green and open spaces is calculated based on demand from the population and the provision of recreational space and is a purely quantitative figure. The degree of provision is 100% when each person living in the city has $8m^2$ of publicly accessible multifunctional open space available within a radius of 400m (Grün Stadt Zürich, 2006). As such, urban open spaces are unroofed public open spaces, such as parks, sports fields, and cemeteries, excluding meadows, pastures, and forest areas.

Supply rate of urban open space is calculated using the formula,

$$Suppy\ rate\ of\ Green\ Space\ (in\ percent) = \frac{offer\ of\ public\ open\ space}{Demand\ of\ open\ space} X\ 100$$

Demand for open space is defined by the number of inhabitants in the area. A supply rate of 100% equates to $8m^2$ of public open space available per inhabitant. A supply rate of 75% or over means good provision of open space, 50-75% means satisfactory provision of open space, 25-50% is unsatisfactory, and 25% or below means poor provision of open space (Grün Stadt Zürich, 2006).

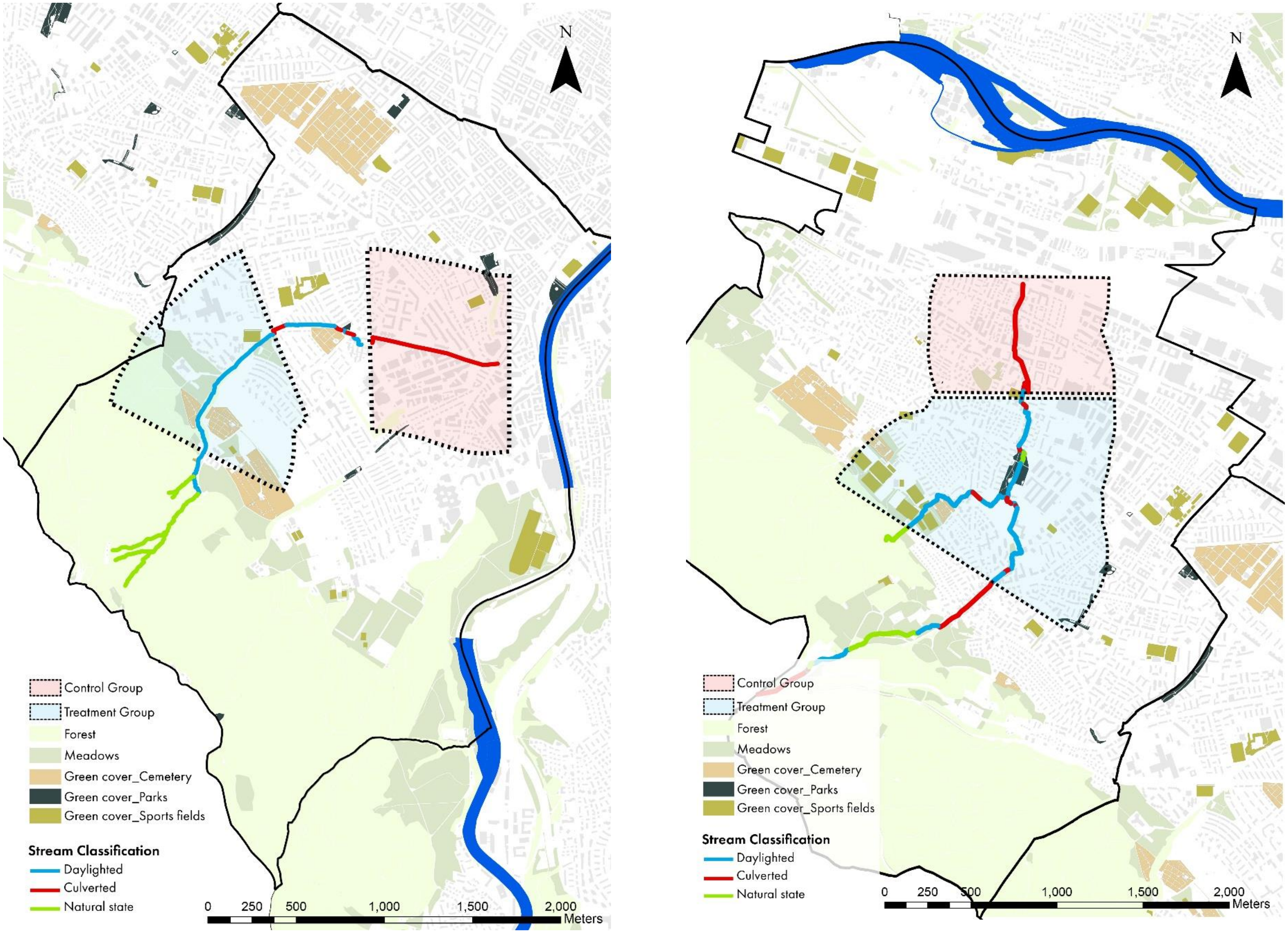


Figure 4.21 Urban open spaces in District 3 (left) and District 9 (right)

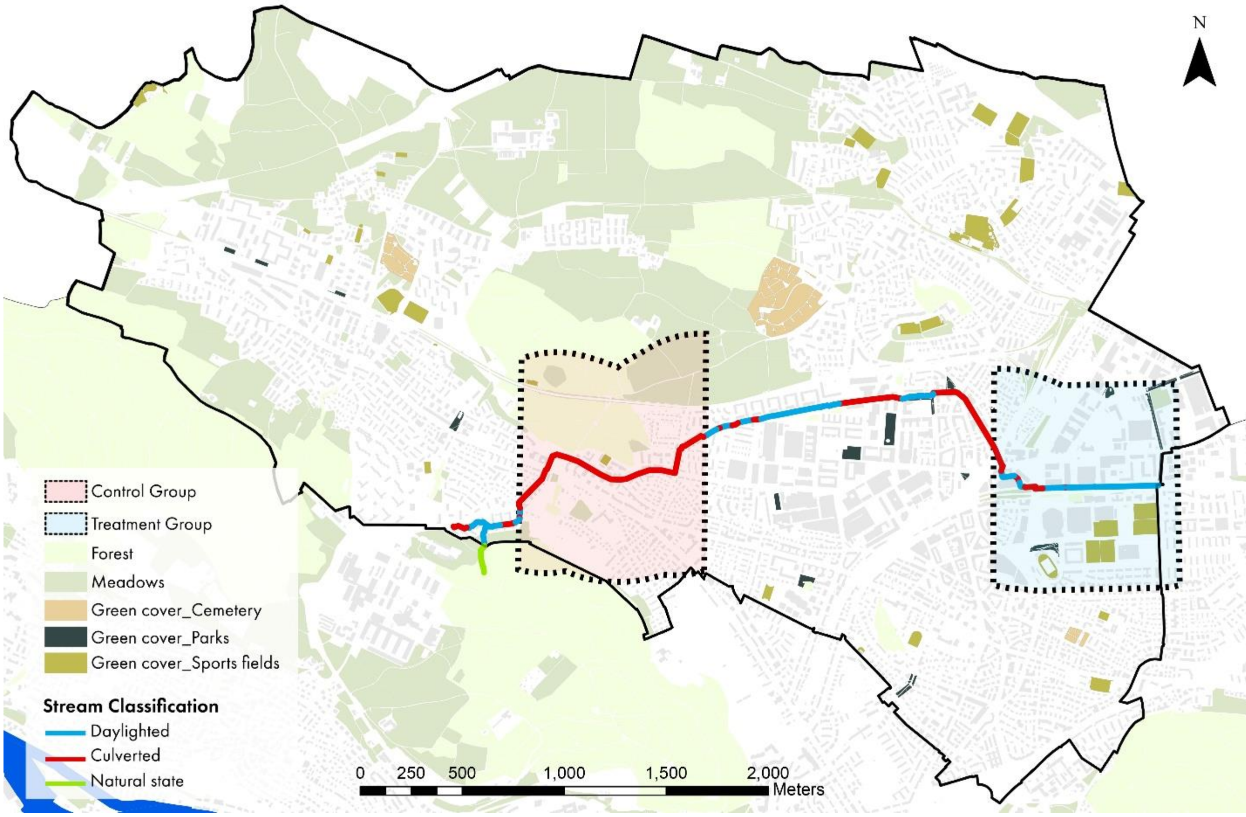


Figure 4.22 Urban open space in District 11

Table 4.10 Area of urban open spaces available to the residents in districts 3, 9, and 11.

Item	**District 3**	**District 9**	**District 11**
Total population	56943	59084	79054
Open space in the urban fabric (sq. m)	465552.11	397190.20	322922.73
Supply rate (%)	**102.2**	**84.0**	**51.1**
Area of open space/ inhabitant (m^2)	**8.2**	**6.7**	**4.1**

From the above table, it is evident that about 8.2 m^2 of urban open space is available per inhabitant, whereas districts 9 and 11 have about 6.7 m^2 and 4.1 m^2 available per inhabitant, respectively. As such, District 3 has a surplus supply of open space at 102 percent, whereas District 9 has a good supply of open space at 84 percent, with District 11 under-provisioned at 51 percent.

4.3.1.1 Open space availability at the local scale

The same formulation is used to examine the availability of open space in the control and the treatment groups. The chart below presents the availability of open space in the control and treatment groups for districts 3, 9, and 11.

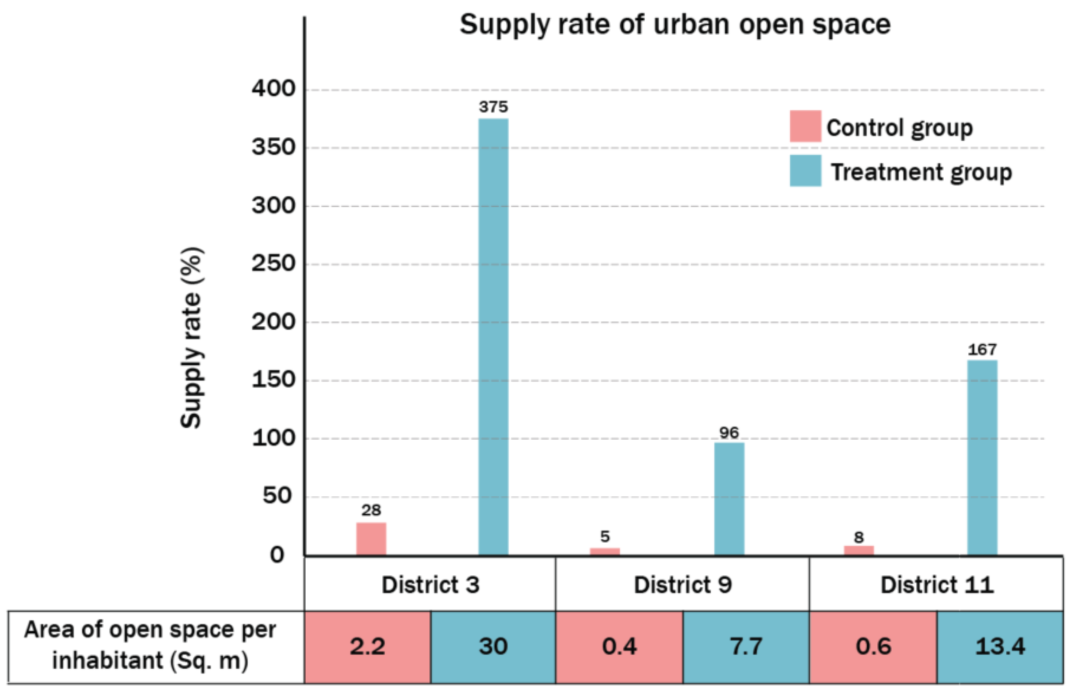


Figure 4.23 Availability of urban open space within the control and treatment groups in districts 3, 9 and 11.

The above chart shows that all three treatment groups have much a higher supply rate and availability of open space per inhabitant than their respective control groups. This proves that stream daylighting in the three districts have increased the availability of the open space, and where stream sections are still in culverts, the supply rate of open space is highly unsatisfactory.

4.4 Discussion and findings

In chapter 2, evidence from the literature suggests that built form holds much potential in enhancing urban resilience. However, limited researchexplicitly focuses on analyzing urban form resilience for stream daylighting as an NbS. Taking this into account, this study aimed to draw from the connections between Kevin Lynch (1981)'s 'fit', and McHarg (1969)'s 'fitting', with urban form attributes to analyse the possible relationship between stream daylighting and urban form in building resilience. The following section expands on the results and explores the relationship between stream daylighting and urban form in enhancing urban resilience.

4.4.1 Analyses at the district scale

At the district scale, the physical properties of the three districts were examined in terms of compactness, diversity, and availability of urban open spaces.

Intuitively, density is a good predictor of the pressure on urban landscapes in growing cities (Alberti, 2008). As one of the most studied variables of density, compactness is often recognized as a feature of sustainable city form (Burton, Jenks and Williams, 2003; Burgees, 2000; Sadowy, 2016). To get a more holistic understanding of the nature of urban form in terms of clustering and dispersion, Moran's Index was used to compute the compactness of population and employment density in districts 3, 9 and 11. This measure of density involving the two variables gives an idea of the composition of urban form in terms of compactness. Furthermore, Hot spot analysis was conducted to determine the exact positioning of high and low clusters within the districts.

<u>The diversity/ mix of a settlement</u>, often perplexed with density, is how different elements of a settlement such as land uses, building types, and lot sizes are mixed in space (Lynch, 1981). Transformation is a highly relevant concept for diversity due to constantly changing social, economic, and environmental contexts (Kostof, 1991; Norton, 2016). Land uses as an element of urban form is the most unstable as it is easily susceptible to change (Norton, 2016). The land use mix for the districts was analyzed using a modified version of Simpson's Diversity Index for the three districts.

<u>Urban open spaces</u> are vital elements in promoting urban resilience in cities. Availability of open spaces provides the city with a certain degree of freedom to accommodate future needs as and when they emerge (Allen et al., 2013; Liu et al., 2014; Sadowy, 2016). The availability of urban open space was calculated based on the offer of public open space in relation to the demand for public open space, which is defined by the number of inhabitants in the area. This specific formulation was used to determine the availability of urban open space in districts 3, 9 and 11.

Table 4.11 Summary of results at the district scale

No.	Indicator	Variables	District 3	District 9	District 11
1	Density	Compactness of population density	*Highly* compact	*Fairly* compact	*Fairly* compact
		Compactness of employment density	*Sprawling* form	*Highly* compact	*Fairly* compact
		Hot-Spot analysis of population density	*Low clusters* in daylighted stream area	*High clusters* in daylighted stream area	*Low clusters* in daylighted stream area
		Hot-Spot analysis of employment density	*Low clusters* in daylighted stream area	*High clusters* in daylighted stream area	*High clusters* in daylighted stream area
2	Diversity	Mix of land uses	*Fairly* diverse (D = 3.34)	*Fairly* diverse (D = 3.44)	*Fairly* diverse (D = 2.86)
3	Open space	Availability of open space	*Good* supply of open space (102%)	*Good* supply of open space (84%)	*Satisfactory* supply of open space (51%)

Table 4.11 presents the summary of results from the analyses conducted at the district scale. Findings indicate that, at <u>District 3</u>, population density is highly compact while the employment density has a sprawling form. Moreover, Hot Spot analyses show that the high cluster areas within the district are not present within the 500m buffer area of the daylighted stream section. Likewise, land uses in District 3 is fairly diverse, with a Diversity Index of 3.34 with a surplus

supply of urban open space with over 8.2 m^2 of open space available per inhabitant in the district. While the district is highly compact, the specific high clusters are not found in close proximity to the daylighted sections of the stream. Thus, the urban form in the district is fairly compact with a high cluster of population density and a low cluster of employment density, while the land uses are fairly diverse with a surplus of urban open spaces in the district. This combination of moderate levels of compactness along with a fair mix of land uses, and a good supply of urban open space supports the claims of resilient urban form.

At District 9, population density and employment density are highly compact and fairly compact, respectively, with the high clusters of population and employment found close to the daylighted sections of the stream. Similar to District 3, District 9 also supports a fairly diverse mix of land uses with a good supply of urban open space with 6.7 m^2 of open space available per inhabitant. Even though the densities are highly compact in the district, this compactness, along with a moderate mix of land uses, and a good supply of open space, supports the notion of resilient urban form.

At District 11, population and employment density is relatively compact, with some high clusters of employment density found in the 500m daylighted buffer area of the stream. Similar to District 3 and District 9, District 11 has a moderate mix of land uses. However, urban open spaces in the district are undersupplied with only 4m^2 of public open space available per inhabitant in the district. This is, however, due to the presence of a large forest area in the middle of the district. The combination of moderate levels of compactness with a fair mix of land uses, and a satisfactory supply of urban open space denotes that the district's overall composition of urban form in the district is fairly resilient.

Thus, to summarize, this analysis at the district scale allows for a more just interpretation of the unique composition of urban form in the three districts, which in turn permits for a holistic interpretation of the results for the variables at the local scale.

4.4.2 Analyses at the local scale

From the results of district-scale analyses, it is evident that the three districts have a fairly resilient composition of urban form. However, to determine if stream daylighting impacted the resilience of urban form, local scale analyses of the urban form attributes such as population density, employment density, diversity of land uses, a mix of lot sizes and the availability of urban open space is calculated for the areas surrounding daylighted sections of the stream and culverted sections of the stream. In addition, construction activity is also compared between the two areas. A 500m buffer along either side of the culverted section of the stream (considered the "control group") and the daylighted section of the stream (considered the "treatment group") is considered to examine the correlation between urban form attributes and stream daylighting.

For the density analyses, first, a Chi-square test for independence was conducted for population and employment density and the means were compared between the two groups. Then, the results were interpreted to check if the densities in the treatment group are more than the densities in the respective control groups to see if daylighting contributes to increased densities in the area. Furthermore, construction activity was compared between the two groups to see if daylighting promoted construction activity in the area.

For the analysis of diversity, Simpson's Diversity Index was used to compare land use mix in the control group and the treatment group. In addition, the mix of lot sizes was also analyzed between the control group and the treatment group to check for power-law relation. Mixture of lot sizes effectively promote mixed-use development, which in turn enhances the flexibility and resilience of urban form to permit incremental change and adaptation (Tuura, 2014, Sharifi, 2019).

Similarly, the availability of urban open spaces was compared between the control group and the treatment group for each district to see if the treatment group supported more open spaces than their respective control groups. Table 4.12, 4.13 and 4.14 summarizes the results for the variables at the local scale in districts 3, 9 and 11, respectively.

Table 4.12 Summary of local scale analyses of the variables in District 3

District 3			
No.	**Variable**	**Control group**	**Treatment group**
1	**Population density**	• *Higher* mean (108 persons/Ha) • *Low* clusters • Low-medium densities	• *Lower* mean (90 persons/Ha) • *Low* clusters • Low-medium densities
2	**Employment density**	• *Higher* mean (179 employees/ha) • *High* clusters • Low-medium densities	• *Lower* mean (105 employees/Ha) • *Low* clusters • Low-medium densities
3	**Construction activity**	*Decrease* in construction activity from 15.4% in 1976-2000 to 7.7% after 2000	*Increase* in construction activity from 5.3% in 1976-2000 to 26.4% after 2000, corresponding the year the stream was daylighted
4	**Diversity of land uses**	*Higher* diversity of land uses (D = 2.8)	*Lower* diversity of land uses (D = 2.6)
5	**Power-law relation of lot sizes**	Lot sizes *follow* power-law relation. (R^2 = 98.7%)	Lot sizes *follow* power-law relation. (R^2 = 93.7%)
6	**Urban open space**	Very *low supply* of open space with only 2.2 m^2 available per inhabitant at 28% supply rate	Very *high supply* of urban open space with 30 m^2 available per inhabitant at 375% supply rate

Table 4.13 Summary of local scale analyses of the variables in District 9

District 9			
No.	**Variable**	**Control group**	**Treatment group**
1	**Population density**	• *Higher* mean (140 persons/Ha) • *High* clusters • Low-medium densities	• *Lower* mean (110 persons/Ha) • *High* clusters • Low-medium densities
2	**Employment density**	• *Higher* mean (137 employees/ha) • *High* clusters • Low-medium densities	• *Lower* mean (74 employees/Ha) • *High* and *low* clusters • Low-medium densities
3	**Construction activity**	Decrease in construction activity from 12.3% in 1976-2000 to 11.3% after 2000	Increase in construction activity from 13% in 1976-2000 to 16.4% after 2000, corresponding the year the stream was daylighted
4	**Diversity of land uses**	*Lower* diversity of land uses (D = 2.3)	*Higher* diversity of land uses (D = 2.9)
5	**Power-law relation of lot sizes**	Lot sizes *follow* power-law relation. (R^2 = 99.2%)	Lot sizes *follow* power-law relation. (R^2 = 99.6%)
6	**Urban open space**	Very *low supply* of open space with only 0.4 m^2 available per inhabitant at 5% supply rate	*High supply* of urban open space with 7.7 m^2 available per inhabitant at 96% supply rate

Table 4.14 Summary of local scale analyses of the variables in District 11

District 11			
No.	**Variable**	**Control group**	**Treatment group**
1	**Population density**	• *Lower* mean (75 persons/Ha) • *Low* clusters • Low-medium densities	• *Higher* mean (92 persons/Ha) • *Low* clusters • Low-medium densities
2	**Employment density**	• *Lower* mean (18 employees/ha) • *Low* clusters • Low-medium densities	• *Higher* mean (203 employees/Ha) • *High* clusters • Low-medium densities
3	**Construction activity**	*Slight increase* in construction activity from 9.8% in 1976-2000 to 10.5% after 2000	*Decrease* in construction activity from 20.2% in 1976-2000 to 13.7% after 2000
4	**Diversity of land uses**	*Lower* diversity of land uses (D = 2.2)	*Higher* diversity of land uses (D = 2.5)
5	**Power-law relation of lot sizes**	Lot sizes *follow* power-law relation. (R^2 = 99.4%)	Lot sizes *follow* power-law relation. (R^2 = 98.4%)
6	**Urban open space**	Very *low supply* of open space with only 0.6 m^2 available per inhabitant at 8% supply rate	*Very high supply* of urban open space with 13.4 m^2 available per inhabitant at 96% supply rate

In District 3, the treatment group's average population and employment densities are comparatively lower than the observed average within the control group. However, none of the high clusters of population density was found in the control group, while low clusters of population and employment density were found in the treatment group. Additionally, a steep increase in construction activity was observed in the treatment group from 5.3% during the years 1976-2000 to 26.4% after the year 2000, corresponding to the year the stream Friesenbergbach was daylighted. Also, Simpson's Diversity Index within the control group was slightly higher at 2.8 compared to 2.6 within the treatment group. The mixture of lot sizes within both the control and treatment group follows a power-law function. Furthermore, a very high supply of urban open space was observed in the treatment group compared to the control group.

In District 9, the control group had a higher average of population and employment densities than the treatment group, while a high cluster of population and employment density is found within both the control and treatment groups. Similar to District 3, there was an increase in construction activity in the treatment group, from 13% between the years 1976-2000 to 16.4% after 2000, corresponding to the year the stream Albeisreider Dorfbach was daylighted. A higher diversity of land uses was observed within the treatment group than the control group, and the lot sizes between the control and treatment group followed the power-law function. Additionally, similar to District 3, the treatment group within District 9 has a very high supply of urban open space than the control group.

In District 11, unlike districts 3 and 9, a higher mean of population and employment density was observed, along with a higher diversity of land uses within the treatment group compared to the control group. In contrast, the construction activity increased in the control group from 9.8% to 10.5%, while it decreased in the treatment group from 20.2% to 13.7%. However, similar to districts 3 and 9, a very high supply of urban open space was observed within the treatment group than the control group.

4.5 Summary

In summary, only one district had higher population and employment densities within the daylighted stream area, whereas two of the three districts had a higher diversity of land uses within the daylighted stream areas. Similarly, an increase in construction activity was observed in two off the three districts studied. However, all the daylighted stream areas support very high percentages of urban open space available for its inhabitants compared to their respective culverted stream sections, which contributes to climate resilience. Thus, there is evidence that in the variables observed, daylighting supports moderate levels of density and diversity around areas surrounding daylighted sections of the stream with a very high supply of urban open space.

4.5.1 Resilience, 'fit', and stream daylighting

Meerow et al. (2016) suggest three dynamic pathways to a resilient state, namely, persistence, transition, and transformation, in their definition of urban resilience. Persistence is the ability to resist disturbance and maintain functions, whereas transition is incremental adaptation, and transformation is the ability to fundamentally and purposefully change or transform (ibid).

The study had its foundations in two major theories: ‘fit’ and ‘fitting’, in building urban form resilience for nature-based solutions. Lynch (1981) defines ‘fit’ as the match between urban form and human behavioural patterns, whereas McHarg (1969) defines ‘fitting’ as the match of natural processes preserved in open space and the pattern of urban development. Moreover, Lynch identifies adaptability, manipulability, and resilience as the indicators of ‘fit’. These two concepts combined are highly relevant to climate adaptation because they allow for “transformative” and “progressive” change in relation to urban landscapes.

Accordingly, the results show that stream daylighting in Zürich has contributed to urban form resilience through the combination of transition and transformation, allowing for incremental adaptation, while also transforming the space to be more resilient. While urban form has the potential to lock in negative or undesired trajectories, results from Zürich prove that stream daylighting can eliminate risks from climate change and further enhance the resilience of urban form.

Density is a good predictor of the pressure on urban landscapes in growing cities (Alberti, 2008). Additionally, compact and walkable neighbourhoods reduce the amount of time required to transport people, goods, and materials and positively influences climate adaptability (Elkin, McLaren, and Hillman, 1991; Jabareen, 2006; Guan, 2017), but there is no optimal density threshold for climate adaptation since it varies for different cities and context. However, moderate density combined with mixed-use zoning and a good supply of urban open space are considered more resilient. As such, the urban form in the daylighted stream areas is more adaptable than in the culverted stream areas, supporting moderate density with a good mix of land uses.

In addition, daylighted areas have access to more urban space in comparison to the culverted stream areas. The presence of urban open spaces is crucial in micro-climate regulation (Chen et al., 2017), reducing air pollution, and minimizing urban heat island effect (Nowak, 1994; Alberti, 1999), which are effective climate adaptation strategies. Moreover, an oversupply of open space provides freedom to accommodate new needs as they arise (Allen et al., 2013; Leon and March, 2014), which enhances the manipulability, thereby positively affecting climate resilience. Together, my findings suggest that stream daylighting in the city of Zürich has enhanced the 'fit' of urban form and urban landscapes to be more adaptable, manipulable, and resilient, enabling incremental adaptation and transformation in the face of climate change.

Chapter 5: Conclusion

Urban sustainability does not depend on physical form alone. Considerable shifts in attitudes and behaviour are also required. Nevertheless, expectations about the magnitude of urban form's influence on building urban resilience are high. It has been estimated that 70% of delivered energy is subject to the influence of land use planning (Barton, 1990). Manipulating land uses and forms is seen as a valuable method of achieving sustainability in cities.

This research aimed to explore the relationship between stream daylighting and urban form in enhancing climate resilience in the City of Zürich. Accordingly, the main objective was to establish an empirical connection between compactness, density, diversity, and the provision of urban open spaces concerning stream daylighting. This study took an experimental approach to analyze the built form of the City of Zürich following the implementation of 'Bachkonzept' or 'stream concept' for daylighting. Based on the quantitative analysis of urban form, it can be concluded that there is a positive correlation between built form and stream daylighting in improving the overall resilience. The results indicate the potential of stream daylighting to improve and build more compact and diverse settlement patterns in addition to providing nature in the city.

The study's theoretical framing combines Lynch's (1981) 'fit' dimension and McHarg's (1969) 'ecological fitting' to draw inferences with respect to physical city form. The study used feature-based urban form attributes such as density, diversity/grain, and supply of urban open space to determine if the urban form in the daylighted areas in Zürich was adaptable, manipulable, and resilient. These variables were applied to analyze the built form characteristics in the daylighted areas at two scales, the district and the local scales, for districts 3, 9 and 11 using geospatial and statistical tools. The following chapter revisits the thesis findings and discusses the contributions and recommendations for future research.

This research aimed to answer the research question: *"how do the urban form characteristics differ between daylighted and culverted sections of the stream? Can daylighting be used as a stimulus to enhance the urban resilience of the built environment in daylighted cities?".* Findings suggest that stream daylighting in the city of Zürich has paved the way for a resilient environment to cope with climatic uncertainties by reducing the risk of vulnerabilities and exposure. The urban form in districts 3, 9 and 11 is compact, diverse, and manipulable with a good supply of urban open spaces. Further, areas surrounding daylighted sections of the stream are more resilient than the areas surrounding culverted sections of the stream. This highlights the importance of monitoring and assessing urban form in changing natural processes. Moreover, the provision of more open spaces through stream daylighting as a nature-based solution must be considered a significant driver of urban change. Stream daylighting provides a new way of defining open spaces without compromising the needs of the growing population in terms of compactness and diversity.

Together, stream daylighting in Zürich has led to an adaptable, manipulable, and resilient city form, emphasizing the need to monitor built form in relation to Nature-based solutions. In addition, this research also addresses the gap in the literature for analyzing built form in relation to stream daylighting as a Nature-based solution. These confirm the hypothesis of the thesis that daylighting has major potential in enhancing the resilience of built form in addition to providing the many ecosystem services and in bringing nature back to the cities.

While this research clearly illustrates the relationship between stream daylighting and urban form, it also raises the question of how urban form can be better planned to accommodate higher densities and future growth, capitalizing on the potential that NbS have in strengthening urban resilience. The methods used in this research provide new insight into analyzing and monitoring the built environment with respect to stream daylighting as an NbS to enhance the potential of stream daylighting in building resilience. Since the methods used in this research are secondary data sources, it allows for generalizability of the results and can be easily mirrored to similar studies to investigate the relationship between Nature-based solutions and built form. Future studies can also compare the urban form of daylighted districts in Zürich with other daylighted projects across cities and scales to check if daylighting enhanced the urban resilience in those cities and if daylighting when perceived as a city-wide policy measure can lead to a more resilient and organic urban form than one-off daylighted projects, such as Cheonggyecheon in Seoul.

Based on the conclusions, practitioners should consider the potential stream daylighting could have to support higher densities and diversities in urban settlements in addition to increased blue-green cover in the city. To better understand the implications of these results, future studies could address how densities and diversities have changed over time along the sections of daylighted streams to get a more detailed outlook of how the urban form has evolved in the event of stream daylighting. Future studies could also include field observations and qualitative data from the site, including interviews with different actors and agents, such as city planners and residents responsible for and using the spaces on a daily basis to get more accurate results. Besides, this research only focused on the 'fit' dimension for evaluating the urban resilience of NbS. Future research can accommodate other dimensions such as vitality and access to better understand the city's physical form and its relation to urban resilience.

References

Aburas, M. M., Ho, Y. M., Ramli, M. F., & Ash'aari, Z. H. (2018). Monitoring and assessment of urban growth patterns using spatio-temporal built-up area analysis. Environmental monitoring and assessment, 190(3), 156.

Ahern, J. (2010). Planning and design for sustainable and resilient cities: Theories, Strategies, and best practices for Green Infrastructure. In V. Novotony, J. Ahern, & P. Brown, Water centric sustainable communities: Planning, Retrofitting, and building the next urban environment (pp. 135-176). John Wiley & sons.

Alberti, M. (1999a). Modeling the urban ecosystem: a conceptual framework. Environment and Planning B: Planning and Design, 26(4), 606-630.

Alberti, M. (1999b). Urban Patterns and Environmental Performance: What Do We Know? Journal of Planning Education and Research, 151-163.

Alberti, M. (2005). The effects of Urban Patterns on Ecosystem Function. International Regional Science Review, 28(2), 168-192. doi:10.1177/0160017605275160

Alberti, M. (2008). Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems. Seattle, Washington: Springer Science+Business Media.

Alberti, M. (2010). Maintaining ecological integrity and sustaining ecosystem function in urban areas. Environmental Sustainability, 178-184. doi:10.1016/j.cosust.2010.07.002

Alberti, M., & Marzluff, J. M. (2004). Ecological resilience in urban ecosystems: Linking urban patterns to human and ecological functions. Urban Ecosystems, 241-265.

Alberti, M., Marzluff, J. M., Bradley, G., Ryan, C., & Zumbrunnen, C. (2003). Integrating Humans into Ecology: Opportunities and Challenges for Studying Urban Ecosystems. BioScience, 53(12), 1169-1179.

Allan, P., Bryant, M., Wirsching, C., Garcia, D., & Teresa Rodriguez, M. (2013). The influence of urban morphology on the resilience of cities following an earthquake. Journal of Urban Design, 18(2), 242–262.

Banai, R., & Rapino, M. A. (2009). Urban Theory since A Theory of Good City Form (1981) - a progress review. Journal of Urbanism, 259-276. doi:10.1080/17549170903466095

Barton H, Grant M (2006) A health map for the local human habitat. J R Soc Promot Heal 126:252–253. doi:10.1177/1466424006070466

Bauduceau, N., Berry, P., Cecchi, C., Elmqvist, T., Fernandez, M., Hartig, T., Krull, W., Mayerhofer, E., N, S., Noring, L., Raskin-Delisle, K., Roozen, E., Sutherland, W., & Tack, J. (2015). Towards an EU Research and Innovation Policy Agenda for Nature-based Solutions & Re-naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-based Solutions and Re-naturing Cities'. Publications Office of the European Union. https://doi.org/10.2777/765301

Beauregard, R. and Lieto, L. (2018) Towards an object-oriented case methodology for planners, in Sanchez, T. W., ed., Planning research and knowledge, Abingdon, UK: Routledge, 153–166.

Behnisch, M., Bräuer, A., Schumacher, U., & Deilmann, C. (2012). Urban Pattern Specification using Spatial Metrics and Density Values. In Enviroinfo (pp. 319-329).

Blackman I. Q., and D. H. Picken (2010). Height and Construction Costs of Residential High-Rise Buildings in Shanghai. Journal of Construction Engineering and Management 136, 1169 – 1180. ISSN: 0733-9364. doi: 10.1061 / (ASCE) CO.1943-7862.0000226.

Bordoloi, R., Mote, A., Sarkar, P. P., & Mallikarjuna, C. (2013). Quantification of land use diversity in the context of mixed land use. Procedia-Social and Behavioral Sciences, 104(0), 563-572.

Bourdic, L., Salat, S., & Nowacki, C. (2012). Assessing cities: a new system of cross-scale spatial indicators. Building research & Infromation, 592-605. doi:https://doi.org/10.1080/09613218.2012.703488

Bowler DE, Buyung-Ali L, Knight TM, Pullin AS (2010) Urban greening to cool towns and cities: a systematic review of the empirical evidence. Landsc Urban Plan 97:147–155. doi:10.1016/j.landurbplan.2010.05.006

Boyko, C. T., & Cooper, R. (2011). Clarifying and re-conceptualising density. Progress in Planning, 1-61.

Brown, K., & Westaway, E. (2011). Agency, capacity, and resilience to environmental change: Lessons from human development, well-being, and disasters. Annual Review of Environment and Resources, 36(1), 321–342. http://dx.doi.org/10.1146/annurev-environ-052610-092905

Bruwier, M., Mustafa, A., Aliaga, D. G., Archambeau, P., Erpicum, S., Nishida, G., ... Dewals, B. (2018). Influence of urban pattern on inundation flow in floodplains of lowland rivers. The Science of the Total Environment, 622-623, 446–458.

Burgess, R. (2000). The compact city debate: A global perspective. Compact cities: Sustainable urban forms for developing countries, 9-24.

Burton, E. (2002). Measuring urban compactness in UK towns and cities. Environment and planning B: Planning and Design, 29(2), 219-250.

Burton, E., Jenks, M., & Williams, K. (Eds.). (2003). The compact city: a sustainable urban form?. Routledge.

Bush, J., & Doyon, A. (2019). Building urban resilience with nature-based solutions: How can urban planning contribute?. Cities, 95, 102483.

Byahut, S., & Mittal, J. (2017). Using land readjustment in rebuilding the earthquake damaged City of Bhuj, India. Journal of Urban Planning and Development, 143(1).

Carl, Peter. 2000. Urban density and block metabolism. In Architecture, city, environment. Proceedings of PLEA 2000, ed. Steemers Koen and Simos Yannas, 343-47. London: James & James.

Carmin, J., Nadkarni, N., & Rhie, C. (2012). Progress and challenges in urban climate adaptation planning: Results of a global survey. Massachusetts Cambridge, MA, USA. http://web.mit.edu/jcarmin/www/urbanadapt/Urban Adaptation Report FINAL.pdf

Carmona, M., Heath, T., Oc, T. and Tiesdell, T. (2003) Public Places Urban Spaces: The Dimensions of Urban Design. Oxford: Architectural Press.

Carpenter, A. (2015). Resilience in the social and physical realms: Lessons from the Gulf Coast. International Journal of Disaster Risk Reduction, 14, 290–301.

Cascio, J. (2009). The next big thing: Resilience. Foreign Policy, 172, 92. http://foreignpolicy.com/2009/09/28/the-next-big-thing-resilience/

Cervero R., and M. Duncan (2006). Which Reduces Vehicle Travel More: Jobs- Housing Balance or Retail-Housing Mixing? Journal of the American Planning Association 72, 475 – 490. doi: 10.1080 / 01944360608976767, ISSN: 0194-4363.

Cervero, R., and K. Kockelman (1997). Travel demand and the 3Ds: Density, diversity, and design. Transportation Research Part D 2 (3):199-219.

Chen, Y.-J., Matsuoka, R. H., & Liang, T.-M. (2017). Urban form, building characteristics, and residential electricity consumption: A case study in Tainan City. Environment and Planning B: Urban Analytics and City Science, 45(5), 239980831769015 933–952.

Cheng V. (2009). Understanding density and high density. In: Designing High-Density Cities for Social and Environmental Sustainability. Earthscan, London; Sterling, VA, pp. 3 – 17. ISBN: 9781844074600.

Clauset, A., Shalizi, C. R., & Newman, M. E. (2009). Power-law distributions in empirical data. *SIAM review*, *51*(4), 661-703.

Conradin, F., & Buchli, R. (2004). The Zürich stream day-lighting program. In Enhancing urban environment by environmental upgrading and restoration (pp. 277-288). Springer, Dordrecht.

Costanza, R., Waigner, L., Folke, C., & Mahler, K.-G. (1993) Modelling complex ecological economic systems: Towards an evolutionary dynamic understanding of people and nature, Bioscience, 43, pp. 545–555.

Creutzig, F., Agoston, P., Minx, J. C., Canadell, J. G., Andrew, R. M., Le Quéré, C., ... & Dhakal, S. (2016). Urban infrastructure choices structure climate solutions. Nature Climate Change, 6(12), 1054-1056.

Daniels, T. (2019). McHarg's theory and practice of regional ecological planning: retrospect and prospect. Socio-Ecological Practice Research, 197-208.

Davoudi, S., Brooks, E., & Mehmood, A. (2013). Evolutionary resilience and strategies for climate adaptation. Planning Practice & Research, 28(3), 307-322. DOI: 10.1080/02697459.2013.787695

Davoudi, S., Shaw, K., Haider, L.J, Allyson, E.Q, Peterson, G.D, Wilkinson, C, Fünfgeld, H., McEvoy, D., Porter, L. (2012) Resilience: a bridging concept or a dead end? "reframing" resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in northern Afghanistan urban resilience: what does it mean in planning practice? Resilience as a useful concept for climate change adaptation? The Politics of Resilience for Planning: A Cautionary Note. Planning Theory & Practice, 13 (2), 299–333.

Dempsey, N., Brown, C., Raman, S., Porta, S., Jenks, M., Jones, C., & Bramley, G. (2010). Elements of Urban Form. In M. Jenks, & C. Jones, Dimensions of Sustainable City (pp. 21-51). Springer Science+Business Media B.V. doi:10.1007/978-1-4020-8647-2_2

Department of the Environment, Transport and the Regions (DETR). (1998). Planning research programme: The use of density in urban planning. London: TSO.

Dodman, D. (2009). Urban density and climate change. Analytical review of the interaction between urban growth trends and environmental changes. Paper prepared for UNFPA. New York, (1), 1-23.

Dugord, P. A., Lauf, S., Schuster, C., & Kleinschmit, B. (2014). Land use patterns, temperature distribution, and potential heat stress risk - the case study Berlin, Germany. *Computers, Environment and Urban Systems, 48*, 86–98.

Durand, C. P., Andalib, M., Dunton, G. F., Wolch, J., & Pentz, M. A. (2011). A systematic review of built environment factors related to physical activity and obesity risk: Implications for smart growth urban planning. Obesity Reviews, 12(501), e173–e182.

EC—European Commission. (2015). Towards an EU Research and Innovation policy agenda for nature-based solutions & re-naturing cities. Final Report of the Horizon2020 Expert Group on Nature-Based Solutions and Re-Naturing Cities. Brussels: European Commission.

Elkin, T., McLaren, D., & Hillman, M. (1991). Reviving the city: Towards sustainable urban development. London: Friends of the Earth.

Ewing R & Cervero R. (2010). Travel and the Built Environment. Journal of the American Planning Association, 76 (3), 265-294

Ewing, R., Pendall, R., Chen, D. 2002. Measuring Sprawl and Its Impacts. Smart Growth America, Washington, DC.

ERZ Entsorgung (2003). Streams in the city of Zürich: Concept, experiences and examples. Zürich, Switzerland, City of Zürich. (translated from German).

Fang, C., Wang, S., & Li, G. (2015). Changing urban forms and carbon dioxide emissions in China: A case study of 30 provincial capital cities. Applied Energy, 158, 519–531.

Feliciotti, A., Romice, O., & Porta, S. (2016). Design for change: five proxies for resilience in the urban form. Open House International, 41(4), 23-30.

Feliciotti, A., Romice, O., & Porta, S. (2017). Design for change: Five proxies for resilience in the urban form. Open House International, 41(4), 23–30.

Feliciotti, A., Romice, O., & Porta, S. (2018). From system ecology to urban morphology: towards a theory of urban form resilience. International Forum on Urbanism, (pp. 1-9).

Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Glob. Environ. Chang. 16 (3), 253–267.

Gill SE, Handley JF, Ennos AR, Pauleit S (2007) Adapting cities for climate change: the role of the green infrastructure. Built Environ 33:115–133

Gleeson, B. (2012). Make no little plans': Anatomy of planning ambition and prospect. Geographical Research, 50(3), 242–255.

Grimm, N. B., Grove, J. M., Pickett, S. T., & Redman, C. L. (2000). ntegrated Approaches to Long-Term Studies of Urban Ecological Systems. BioScience, 50(7), 571-584.

Grubler A., B. O'Neill, K. Riahi, V. Chirkov, A. Goujon, P. Kolp, I. Prommer, S. Scherbov, and E. Slentoe (2007). Regional, national, and spatially explicit scenarios of demographic and economic change based on SRES. Technological Forecasting and Social Change 74, 980 – 1029. doi: 10.1016 / j.techfore. 2006.05.023, ISSN: 0040-1625.

Grübler, Arnulf, and David Fisk (eds) (2013). Energizing Sustainable Cities: Assessing Urban Energy. Abingdon, United Kingdom: Routledge.

Grün Stadt Zürich (Ed.). (2006). Das Grünbuch der Stadt Zürich (The green-book ofthe city of Zurich, Zürich – City of Zurich). Retrieved from http://www.stadt-zuerich.ch/content/dam/stzh/ted/Deutsch/gsz/Angebote%20und%20Beratung/Publikationen%20und%20Broschueren/Publikationen/Gruenbuch-gesamt pdf.pdf

Guan, C. (2018). Spatial metrics of urban form: Measuring compact cities in China. In Vertical Urbanism (pp. 189-209). Routledge.

Hachem, C. (2016). Impact of neighborhood design on energy performance and GHG emissions. *Applied Energy*, *177*, 422–434.

Hachem, C., Athienitis, A., & Fazio, P. (2012). Evaluation of energy supply and demand in solar neighborhood. Energy and Buildings, 49, 335–347.

Hamin, E. M., & Gurran, N. (2009). Urban form and climate change: Balancing adaptation and mitigation in the U.S. and Australia. Habitat International, 33(3), 238–245.

Hartig T, Mitchell R, de Vries S, Frumkin H (2014) Nature and health. Annu Rev Public Health 35:207–228. doi:10.1146/annurev-publhealth-032013-182443

Haughey, R. M. (2005). High-density development: Myth and fact. Washington, DC: Urban Land Institute

Hayek, U. W., Efthymiou, D., Farooq, B., von Wirth, T., Teich, M., Neuenschwander, N., & Grêt-Regamey, A. (2015). Quality of urban patterns: Spatially explicit evidence for multiple scales. Landscape and Urban Planning, 142, 47-62.

Huang, J., Lu, X. X., & Sellers, J. M. (2007). A global comparative analysis of urban form: Applying spatial metrics and remote sensing. Landscape and urban planning, 82(4), 184-197.

Hubbart, J. A., Kellner, E., Hooper, L., Lupo, A. R., Market, P. S., Guinan, P. E., ... Svoma, B. M. (2014). Localized climate and surface energy flux alterations across an urban gradient in the central US. *Energies*, *7*(3), 1770–1791.

Hui, S. C. (2001). Low energy building design in high density urban cities. *Renewable Energy, 24*(3), 627–640.

IIASA (2009). GGI Scenario Database Version 2.0.1. Available at: http://www.iiasa.ac.at/Research/GGI/DB.

IPCC (2012). In C. B. Field, V. Barros, T. F. Stocker, D. Qin, D. J. Dokken, K. L. Ebi, ... P. M. Midgley (Eds.). Managing the risks of extreme events and disasters to advance climate change adaptation. A special report of working groups I and II of the intergovernmental panel on climate change. Cambridge, UK, and New York, NY, USA: Cambridge University Press.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp

Jabareen, Y. R. (2006). Sustainable urban forms: Their typologies, models, and concepts. Journal of planning education and research, 26(1), 38-52.

Jackson, L. E. (2003). The relationship of urban design to human health and condition. Landscape and Urban Planning, 64(4), 191–200.

Jacobs, J. (1961) The Death and Life of Great American Cities. New York: Random House Inc.

Jacobs, J. (1969) The Economy of Cities. New York: Random House Inc.

Jahanmiri, F. (2015). *Making Sense of the Fractal Urban Form and Function: an Agent-Based Modelling Approach* (Master's thesis, University of Waterloo).

Jenks, M., & Dempsey, N. (Eds.). (2005). The language and meaning of density. Future forms and design for sustainable cities (pp. 287–309). Oxford: Architectural Press.

Jenks, M., Burton, E., & Williams, K. (Eds.). (1996). The compact city: A sustainable urban form? London: E & FN Spon.

Kaye, J. P., Groffman, P. M., Grimm, N. B., Baker, L. A., & Pouyat, R. V. (2006). A distinct urban biogeochemistry? TRENDS in Ecology and Evolution, 21(4), 192-199.

Khirfan, L. (2020a). The New Climate Urbanism: A Physical, Social, and Behavioural Framework. In Climate Urbanism (pp. 171-193). Palgrave Macmillan, Cham.

Khirfan, L., Mohtat, N., & Peck, M. (2020b). A systematic literature review and content analysis combination to "shed some light" on stream daylighting (Deculverting). Water Security, 1-10. doi:https://doi.org/10.1016/j.wasec.2020.100067

Khirfan, L., Peck, M. L., & Mohtat, N. (2020c). Digging for the truth: A combined method to analyze the literature on stream daylighting. Sustainable Cities and Society, 59 , 1-12. doi:https://doi.org/10.1016/j.scs.2020.102225

Kostof, S. (1991) The City Shaped. London: Thames and Hudson Ltd.

Kropf, K. (2009). Aspects of urban form. Urban morphology, 13(2), 105.

Kropf, K. (2014). Ambiguity in the definition of built form. Urban Morphology, 18(1), 41–57.

Kropf, K. (2018). The handbook of urban morphology. Wiley.

Lautenschütz, A.-K., & Jeanneret, B. (2017). *Living in cities: a comparison between the larger core cities and their commuting zones.* Federal Statistical Office (FSO).

Lehmann, S. (2016). Sustainable urbanism: Towards a framework for quality and optimal density? Future Cities and Environment, 2(1).

Leichenko, R. (2011). Climate change and urban resilience. Current Opinion in Environmental Sustainability, 3(3), 164–168. http://dx.doi.org/10.1016/j.cosust.2010.12.014

Leon, J., & March, A. (2014). Urban morphology as a tool for supporting tsunami rapid resilience: A case study of Talcahuano, ChileD. Habitat International, 43, 250–262.

Liu, L., Lin, Y., & Wang, S. (2014). Urban design for post-earthquake reconstruction: A case study of Wenchuan County, China. Habitat International, 41, 290–299.

Lowe, M., Boulange, C., & Giles-Corti, B. (2014). Urban design and health: Progress to date and future challenges. Health Promotion Journal of Australia, 25(1), 14–18.

Lucon O., D. Ürge-Vorsatz, A. Zain Ahmed, H. Akbari, P. Bertoldi, L. F. Cabeza, N. Eyre, A. Gadgil, L. D. D. Harvey, Y. Jiang, E. Liphoto, S. Mirasgedis, S. Murakami, J. Parikh, C. Pyke, and M. V. Vilariño, 2014: Buildings. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lynch, K. (1981). A Theory of Good city form. Massachusetts Institute of Technology.

Marcus, L., & Colding, J. (2011). Towards a spatial morphology of urban social-ecological systems. In 18th International Seminar on Urban Form.

Marcus, L., & Colding, J. (2014). Toward an integrated theory of spatial morphology and resilient urban systems. Ecology and Society, 19(4).

McGarigal, K. (2015). Fragstats Help. Amherst: University of Massachusetts.

McHarg, I. (1969). Design with Nature. New York: The National History Press.

Meerow, S., & Newell, J. P. (2015). Resilience and complexity: A bibliometric review and prospects for industrial ecology. Journal of Industrial Ecology, 19(2),236–251. http://dx.doi.org/10.1111/jiec.12252

Meerow, S., Newell, J. P., & Stults, M. (2016). Defining urban resilience: A review. *Landscape and urban planning*, *147*, 38-49.

Montgomery, J. (1998). Making a city: Urbanity, vitality and urban design. Journal of Urban Design, 3(1), 93-116. doi:10.1080/13574809808724418

Muratori, S. (1959) Studi per una operante storia urbana di Venezia. Rome, Italy: Istituto Poligraphico dello Stato.

Ndubisi, F. O. (2014). The Ecological Design anf Planning Reader. Island Press.

Nelson, A. C. (2004) Toward a New Metropolis: the Opportunity to Rebuild America, Brookings Institute, Washington, DC

Nielsen, T. A. S. (2015). Changes in transport behavior during the financial crisis. An analysis of urban form, location and transport behavior in the greater Copenhagen area 2006–2011. Research in Transportation Economics, 51, 10–19.

Norton, C. A. (2016). The role of fine urban grain in securing the diversity of the urban centre (Doctoral dissertation).

Nowak, D.J. 1994. Air pollution removal by Chicago's urban forest. In Chicago Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project, eds. E.G. McPherson, D.J. Nowak, and A. Rountree, 3-18. Radnor, Pa: Northeastern Forest Experiment Station.

Oliveira, V. (2016). Urban Morphology: An Introduction to the Study of the Physical Form of Cities. Springer International Publishing Switzerland.

Owen, D. (2009). Green metropolis: Why living smaller, living closer, and driving less are the keys to sustainability. New York: Riverhead Books.

Parker, Terry. 1994. The land use—air quality linkage: How land use and transportation affect air quality. Sacramento: California Air Resources Board.

Pattacini, L. (2012). Climate and urban form. URBAN DESIGN International, 17, 106-114. Picken D. H., and B. D. Ilozor (2003). Height and construction costs of buildings in Hong Kong. Construction Management and Economics 21, 107 – 111.

Pickett, S. T., Cadenasso, M. L., Grove, J. M., Nilon, C. H., Pouyat, R. V., Zipperer, W. C., & Costanza, R. (2001). Urban Ecological Systems: Linking Terrestrial Ecological, Physical, and Socioeconomic Components of Metropolitan Areas. Annual Review of Ecology and Systematics, 127-157. Retrieved from https://www.jstor.org/stable/2678637

Pickett, S., Cadenasso, M., & Brian, M. (2013). Resilience in Ecology and Urban Design: Linking Theory and Practice for Sustainable Cities (Vol. 3). Springer Netherlands. doi:10.1007/978-94-007-5341-9

Pinkham, R. (2000). Daylighting: New life for buried streams. Colarado: Rocky Mountain Institute.

Pont, B. M., & Haupt, P. (2007). The relation between urban form and density. Urban Morphology, 11(1), 142-146.

Ponzini, D. (2018) The unwarranted boundaries between urban planning and design in theory, practice and research, in Sanchez, T. W., ed., Planning research and knowledge, Abingdon, UK: Routledge, 182–195.

Rapoport, A. (1975). Toward a redefinition of density. Environment and Behavior, 7(2), 133–158.

Ratti, C., Baker, N., & Steemers, K. (2005). Energy consumption and urban texture. Energy and Buildings, 37, 762-776. doi:10.1016/j.enbuild.2004.10.010

Reid, W., Mooney, H., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., … Zurek, M.B.(2005). Ecosystems and Human Well-being: Synthesis. Washington, USA: Island Press

Rode, P., Keim, C., Robazza, G., Viejo, P., & Schofield, J. (2014). Cities and energy: urban morphology and residential heat-energy demand. Environment and Planning B: Planning and Design, 41, 138-162. doi:10.1068/b39065

Sadowy, K. (2016). Sustainable city – Flexible or durable? Socio-economics aspects of urban patterns.

Salat S. (2011). Cities and Forms: On Sustainable Urbanism. Hermann, 544 pp. ISBN: 2705681116.

Salat, S. (2013). The life of urban forms, sustainable building and refurbishment for next generations. 15–20.

Salat, S. (2017). A systemic approach of urban resilience: power laws and urban growth patterns. *International Journal of Urban Sustainable Development*, *9*(2), 107-135.

Scheer, B. C. (2017). Urban Morphology as a research method. In T. W. Sanchez, Planning Knowledge and research (pp. 167-181). Routledge. doi:10.4324/9781315308715-11

Schwarz, N. (2010). Urban form revisited—Selecting indicators for characterising European cities. Landscape and urban planning, 96(1), 29-47.

Seelig, S. (2011). A master plan for low carbon and resilient housing: The 35 ha area in Hashtgerd New Town, Iran. Cities, 28(6), 545–556.

Seto K. C., S. Dhakal, A. Bigio, H. Blanco, G. C. Delgado, D. Dewar, L. Huang, A. Inaba, A. Kansal, S. Lwasa, J. E. McMahon, D. B. Müller, J. Murakami, H. Nagendra, and A. Ramaswami, 2014: Human Settlements, Infrastructure and Spatial Planning. In: Climate Change Change. Contribution of Working Group III to the Fifth Assessment Report of the 2014: Mitigation of Climate Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Sharifi, A. (2016). From Garden City to Eco-urbanism: The quest for sustainable neighborhood development. Sustainable Cities and Society, 20, 1-16.

Sharifi, A. (2019a). Resilient urban forms: A macro-scale analysis. Cities, 85, 1–14.

Sharifi, A. (2019b). Resilient urban forms: A meso-scale analysis. Cities, 93, 238-252.

Sharifi, A. (2019c). Resilient urban forms: A review of literature on streets and street networks. Building and Environment, 147, 171-187. doi:https://doi.org/10.1016/j.buildenv.2018.09.040

Sharifi, A., & Yamagata, Y. (2018). Resilience-oriented urban planning. In Resilience-Oriented Urban Planning (pp. 3-27). Springer, Cham.

Silva, M., Oliveira, V., & Leal, V. (2017). Urban form and energy demand: A Review of Energy-relevant Urban Attributes. Journal of Planning Literature, 32(4), 088541221770690. https://doi.org/10.1177/0885412217706900 346–365.

Smith, Tara, Maurice Nelischer, and Nathan Perkins. (1997). Landscape and Urban Planning 39:229–241.

Stangl, P. (2018). Prospects for urban morphology in resilience assessment. In Y. Yamagata, & A. Sharifi (Eds.). Resilience-oriented urban planning: Theoretical and empirical insights (pp. 181–193). Cham: Springer International Publishing.

Stanley, B. W., Stark, B. L., Johnston, K. L., & Smith, M. E. (2012). Urban open spaces in historical perspective: A transdisciplinary typology and analysis. Urban Geography, 33(8), 1089–1117.

Steiner, F. (2017). Healing the Earth: The Relevance of Ian McHarg's Work for the future. Hunab Ecology Review, 75-85. doi:dx.doi.org/10.22459/HER.23.02.2017.08

Swanstrom, T. (2008) Regional resilience: A critical examination of the ecological framework, IURD Working Paper Series, (Berkeley, CA: Institute of Urban and Regional Development, UC Berkeley).

Talen, E. (1999). Sense of community and neighbourhood form: An assessment of the social doctrine of new urbanism. Urban studies, 36(8), 1361-1379.

Talen, E. (2005). Land Use Zoning and Human Diversity: Exploring the Connection. Journal of Urban Planning and Development, 131(4), 214-232. doi:10.1061/(ASCE)0733-9488(2005)131:4(214)

Talen, E. (2006). Design That Enables Diversity: The Complications of a Planning Ideal. Journal of Planning Literature, 20(3), 233-249. doi:10.1177/0885412205283104

Tsai, Y. H. (2005). Quantifying urban form: compactness versus' sprawl'. Urban studies, 42(1), 141-161.

Tuura, L. (2014). Juxtapositions of density: A study of the relationship of urban form to abrupt variations in density.

UN DESA (2013). Population Density and Urbanization. Available at: http://unstats.un.org/unsd/demographic/sconcerns/densurb/densurbmethods.htm.

UNDESA (2012). World Urbanization Prospects: The 2011 Revision. United Nations Department of Economic and Social Affairs, Population Division, New York.

UNDESA (2018). World urbanization prospects: The 2018 revision. United Nations, Department of Economic and Social Affairs.

Urban Task Force. (2005). Towards a strong urban renaissance. London: HMSO.

Venerandi, A., Quattrone, G., & Capra, L. (2018). A scalable method to quantify the relationship between urban form and socio-economic indexes. EPJ Data Science, 7(1), 4.

Venerandi, A., Zanella, M., Romice, O., Dibble, J., & Porta, S. (2017). Form and urban change – An urban morphometric study of five gentrified neighbourhoods in London. Environment and Planning B: Urban Analytics and City Science, 44(6), 1056–1076.

Vernez Moudon, A. (1994) Getting to know the built landscape: Typomorphology. In: K. Franck and L.H.

Villagra, P., Rojas, C., Ohno, R., Xue, M., & Gomez, K. (2014). A GIS-base exploration of the relationships between open space systems and urban form for the adaptive capacity of cities after an earthquake: The cases of two Chilean cities. Applied Geography, 48, 64–78.

Whitehand, J. W. (2001). British urban morphology: The Conzenion tradition. Urban Morphology, 5(2), 103–109.

Whitehand, J.W.R. (ed.) (1981) The Urban Landscape: Historical Development and Management, Papers by M.R.G. Conzen. London: Academic Press.

Wild, T., Bernet, J. F., Westling, E. L., & Lerner, D. N. (2011). Deculverting: reviewing the evidence on the 'daylighting' and restoration of culverted rivers. Water and Environmental Jpurnal, 412-421. doi:10.1111/j.1747-6593.2010.00236.x

Williams, K., Burton, E., & Jenks, M. (Eds.). (2000). Achieving sustainable urban form. London: E & FN Spon.

Williams, K., Joynt, J. L. R., & Hopkins, D. (2010). Adapting to climate change in the compact city: The suburban challenge. Built Environment, 36(1), 105–115.

Ye, Y., Li, D., & Liu, X. L. (2018). How block density and typology affect urban vitality: an exploratory analysis in Shenzhen, China. Urban Geography, 631-652.

Yildiz, S., & Doker, M. F. (2016). Monitoring urban growth by using segmentation-classification of multispectral Landsat images in Izmit, Turkey. Environmental Monitoring and Assessment, 188(7), 1–12.

Zielinski, K. 1979. Experimental analysis of eleven models of urban population density. Environment and Planning A 11(6):629–641.