ENVIRONMENTAL REGENERATION THROUGH GREEN INFRASTRUCTURE: A CASE STUDY OF REGIO PARCO IN TURIN

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M.Sc Thesis

ENVIRONMENTAL REGENERATION THROUGH GREEN INFRASTRUCTURE: A CASE STUDY OF REGIO PARCO IN TURIN

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Dedication

This thesis is dedicated to the unwavering pillar of strength in my life – my beloved Mother Osaemwenkhae Omorovbiye. Her selfless sacrifices, boundless encouragement, and unwavering commitment to my education have been the driving force behind my academic journey. In every challenge faced and every milestone achieved, her enduring support has been my greatest motivation. This dedication is a tribute to her love, resilience, and the countless sacrifices she has made to ensure my success.

I extend my deepest gratitude to my esteemed supervisors Ingaramo Roberta, Pollo Ricardo and co-supervisor Anja Pejović whose guidance and supervision have been invaluable throughout this academic endeavor. Their expertise, insights, and constructive feedback have played a pivotal role in shaping the quality and direction of this research.

To the almighty God, I offer heartfelt thanks for granting me the strength, wisdom, and grace to persevere through the challenges of this research. It is through divine guidance that I have found the fortitude to navigate the complexities of academia and complete this significant undertaking.

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Glossary

Albedo: The reflectivity of a surface, particularly the percentage of incoming sunlight reflected back into the atmosphere. High albedo surfaces, like white rooftops, can reduce heat absorption and mitigate the urban heat island effect. (Akbari et al., 2016)

Biodiversity: The variety of plant and animal life in a particular habitat, enhanced by green infrastructure. (Bowler et al., 2010).

Cost-Benefit Analysis: Evaluation of the economic feasibility of a project by comparing its costs to the benefits it delivers. (Liu et al., 2016).

Economic Valuation: Assessment of the economic benefits of green infrastructure projects, considering both monetary and environmental gains. (Van Oijstaeijen et al., 2020).

ENVI-met Software: A microclimate simulation tool used for assessing environmental parameters before and after interventions. (Sangiorgio et al., 2020).

Environmental Regeneration: The revitalization and improvement of urban environments through sustainable practices. (Laureti et al., 2018).

Environmental Parameters: The measurable aspects of the environment, including air and surface temperatures, wind speed, and physiological equivalent temperature. (Taleghani et al., 2019).

Evapotranspiration: Combined water loss from evaporation and plant transpiration, contributing to cooling effects. (Bowler et al., 2010).

Green Infrastructure: An approach utilizing natural elements such as green roofs, green walls, and permeable pavements to address environmental issues and enhance urban sustainability. (Gill et al., 2007; Belčáková et al., 2019)

Hedonic Pricing Model: An economic model assessing the impact of green infrastructure on property values. (Nazir et al., 2015).

Infiltration Systems: Techniques allowing the gradual movement of water into the soil, preventing surface runoff and improving groundwater levels. (Balany et al., 2020).

Microclimate Analysis: The study of climate conditions at a small scale, often applied to evaluate the impact of interventions on temperature, wind speed, and comfort. (Taleghani et al., 2019)

Nature-Based Solution: An approach to urban planning and development that integrates natural elements, such as green spaces and water features, to address environmental challenges. Nature-based solutions are integral to green infrastructure strategies. (Belčáková et al., 2019)

Physiological Equivalent Temperature (PET): A measure combining air temperature, humidity, and wind speed to assess the perceived thermal comfort of individuals. (Saaroni et al., 2018).

Urban Form: The physical layout and design of urban spaces, impacting heat retention and distribution. (Evola et al., 2017).

Urban Heat Island (UHI): The elevated temperature in urban areas compared to their rural surroundings, primarily due to human activities and modifications. (Oke, 1982; Phelan et al., 2015).

Urban Canyon: The street space between buildings, characterized by the height-to-width ratio of the surrounding structures. It influences solar access, ventilation, and heat retention, contributing to the urban microclimate. (Oke, 1982)

Abstract

Urbanization has ushered in unprecedented challenges, notably the rise of Urban Heat Islands (UHI), wherein metropolitan areas experience elevated temperatures compared to their rural counterparts. These thermal disparities have far-reaching consequences on human comfort, energy consumption, and overall urban well-being. In response to this, the concept of green infrastructure emerges as a pivotal strategy for mitigating UHI effects and fostering environmental regeneration within urban spaces. The phenomenon of Urban Heat Islands is multifaceted, influenced by intricate interactions between natural and anthropogenic factors. Notably, surface materials, land use changes, and anthropogenic heat contribute significantly to the exacerbation of UHI (Phelan et al., 2015; Yang et al., 2020; Zölch et al., 2016). The repercussions are felt on both macro and micro scales, affecting cities globally. Turin, exemplifying the broader urban conundrum, has embarked on an innovative approach towards environmental regeneration through the strategic implementation of green infrastructure.

This thesis navigates through a tripartite structure, sequentially unraveling the layers of this complex issue. The initial segment delves into comprehensive research, fusing an exploration of the UHI phenomenon with the state-of-the-art insights into green infrastructure. Herein, the significance of urban greening, diverse typologies of green infrastructure, and economic valuations of such projects are meticulously examined. This foundational phase sets the stage for understanding the intricacies of UHI and how green infrastructure can be wielded as a potent tool for urban regeneration. The subsequent phase involves an in-depth examination of five global architectural and urban projects that have successfully integrated green infrastructure. By scrutinizing the lessons gleaned from these international endeavors, the study distills a practical understanding of effective strategies and potential pitfalls. This experiential lens aids in shaping a nuanced approach towards implementing green infrastructure in the unique context of Regio Parco, Turin.

The concluding segment transitions from theoretical underpinnings to practical application, focusing on the environmental regeneration project in Quartiere S1Corso Taranto, Turin. The interdisciplinary nature of this phase incorporates architectural, urban, and environmental considerations. The integration of green roofs, green walls, permeable paving, and other innovative strategies is envisioned to permeate both building and neighborhood scales, fostering a holistic transformation from individual building facades to the fabric of the entire community. In navigating through these phases, this thesis seeks not only to contribute to the academic discourse surrounding UHI mitigation and green infrastructure but also to offer a tangible blueprint for the sustainable revitalization of urban spaces. Turin, emblematic of many contemporary cities grappling with urbanization challenges, stands as a microcosm for this endeavor. Through an amalgamation of research, international insights, and on-the-ground application, this thesis aspires to be a catalyst for a more sustainable and resilient urban future.

Introduction

Urbanization and the rapid growth of cities have led to numerous environmental challenges, with urban heat island (UHI) effect being one of the most critical issues. The urban heat island effect refers to the phenomenon where urban areas experience significantly higher temperatures than their surrounding rural areas due to various anthropogenic factors. This effect has adverse impacts on human health, energy demand, air quality, and urban ecosystems. Research by Bowler et al. (2010) highlights the need for empirical evidence on the effectiveness of urban greening in cooling towns and cities. Phelan et al. (2015) provide an overview of the mechanisms, implications, and possible remedies for UHI, emphasizing the urgent need for mitigation strategies. As cities continue to expand, it becomes imperative to explore sustainable and effective strategies to mitigate UHI and promote environmental regeneration. One such approach gaining increasing attention is the implementation of green infrastructure. Green infrastructure (GI) has emerged as a promising approach to mitigate UHI effects and promote environmental regeneration. This state of the art provides an overview of relevant literature to establish the effectiveness of GI in mitigating the urban heat island effect. The effectiveness of green infrastructure in mitigating the UHI effect has been extensively studied in the academic literature.

A systematic review conducted by Bowler et al. (2010) examined the empirical evidence on urban greening and its cooling effect on towns and cities. They found that green spaces, especially trees and vegetation, can significantly lower air temperatures and provide shading, thus mitigating the UHI effect. Similarly, studies by Taleghani et al. (2014), Phelan et al. (2015), and Akbari et al. (2016) have explored various heat mitigation strategies and highlighted the potential of green infrastructure in cooling urban environments. Green infrastructure encompasses natural and semi-natural elements integrated into urban environments to provide ecological, social, and economic benefits. Various components of GI, such as urban forests, green roofs, green walls, and permeable surfaces, can contribute to UHI mitigation by providing shade, evapotranspiration, and reducing surface and air temperatures. The review by Zölch et al. (2016) evaluates the heat mitigation measures of GI at the micro-scale, emphasizing the role of vegetation and cool materials. Evola et al. (2017) emphasize the potential of GI in improving outdoor thermal comfort in dense and old neighborhoods.

To evaluate the effectiveness of GI in mitigating UHI, various indicators and metrics are used, including land surface temperature, air temperature, and thermal comfort indices. Taleghani et al. (2014) conduct a parametric study to validate and calibrate heat mitigation strategies for urban courtyards in the Netherlands. They emphasize the importance of understanding the impact of GI interventions on microclimates and human comfort. Saaroni et al. (2018) provide a survey of research methodologies and findings across different climatic regions, highlighting the need for robust monitoring and modeling approaches.
Assessing the economic benefits and costs associated with GI interventions is crucial for decision-making and policy development. Economic valuation methods, such as cost-benefit analysis and hedonic pricing, can quantify the monetary value of GI benefits. Perini and Rosasco (2013) examine the economic valuation of green facades and living wall systems, while Hsu and Chao (2020) assess the economic valuation of GI investments in urban renewal. Social acceptance and community engagement play a vital role in the successful implementation of GI interventions. Mansor and Said (2008) highlight the importance of green infrastructure networks as social spaces for the well-being of residents.

Research Questions

What is the meaning of the term **"Green Infrastructure"?.** Definitions, origins, frameworks, and typologies.

What **innovative tools, technologies, and strategies** can be employed to enhance the design and implementation of Green Infrastructure projects?.

What are the methods of valuation of **Green Infrastructure projects** in the context of environmental regeneration?.

The **effectiveness of the implementation of green infrastructure** in urban regeneration?.

In what **ways** can the **redesign of outdoor spaces,** transformation of courtyards, and modifications to building facades enhance **social interactions** and **foster a sense of community** in the regenerated urban environment?.

Methodology

The methodology employed in this thesis entails a comprehensive approach that integrates research, case studies, and practical implementation. The thesis is divided into three main parts: **Research on green infrastructure, Case studies, and Environmental regeneration project of District S1 neighbourhood of Corso Taranto, Turin.** The methodology for each phase is outlined below:

Part 1. Research on Green Infrastructure:
a. Urban Heat Island (UHI) Investigation:
- Objective: To understand the phenomenon of UHI and its implications.
- Methods: Literature review of studies on UHI, its definition, significance, and impact on urban environments.
-Tools: Academic databases, scholarly articles, and relevant books.

b. State of the Art of Green Infrastructure:
- Objective: To establish a foundation for implementing effective green infrastructure strategies.
- Methods:
  - Literature review on the definition and typologies of green infrastructure.
  - Exploration of various scales of green infrastructure implementation.
  - Examination of economic valuation methodologies for green infrastructure projects.
  - Identification and analysis of innovative tools and strategies.

c. Economic Valuation of Green Infrastructure:
- Objective: To assess the economic feasibility and benefits of green infrastructure.
- Methods:
  - Review of studies conducting cost-benefit analysis for green infrastructure.
  - Evaluation of economic and environmental returns on investment.
  - Identification of key economic indicators.

Part 2. Case Studies:
a. Architectural and Urban Projects Analysis:
- Objective: Extract lessons from international projects that successfully implemented green infrastructure.
- Methods:
  - In-depth study of six selected projects.
  - Analysis of project documentation, design strategies, and outcomes.

Phrase 3. Environmental Regeneration Project of District S1 Corso Taranto, Turin:
a. Site Analysis or Contextual Study:
- Objective: Understand the current state of District S1 Corso Taranto and identify areas for intervention.
- Methods:
  - Site visits for firsthand observation.
  - Analysis of existing infrastructure, landscape, and built environment.

b. Microclimate Analysis using ENVI-met Software:

- Objective: To evaluate the impact of green infrastructure interventions on microclimatic conditions.
- Methods:
  - Collection of meteorological data.
  - Utilization of ENVI-met software to simulate potential air temperature, surface temperature, wind speed, and PET.
  - Analysis of the microclimate outputs

Conclusion and Recommendations:

- Objective: To synthesize findings and propose recommendations.
- Methods:
  - Comprehensive analysis of research, case studies, and project implementation.
  - Identification of broader implications and scalability of proposed interventions.
  - Recommendations for future urban regeneration projects based on lessons learned.

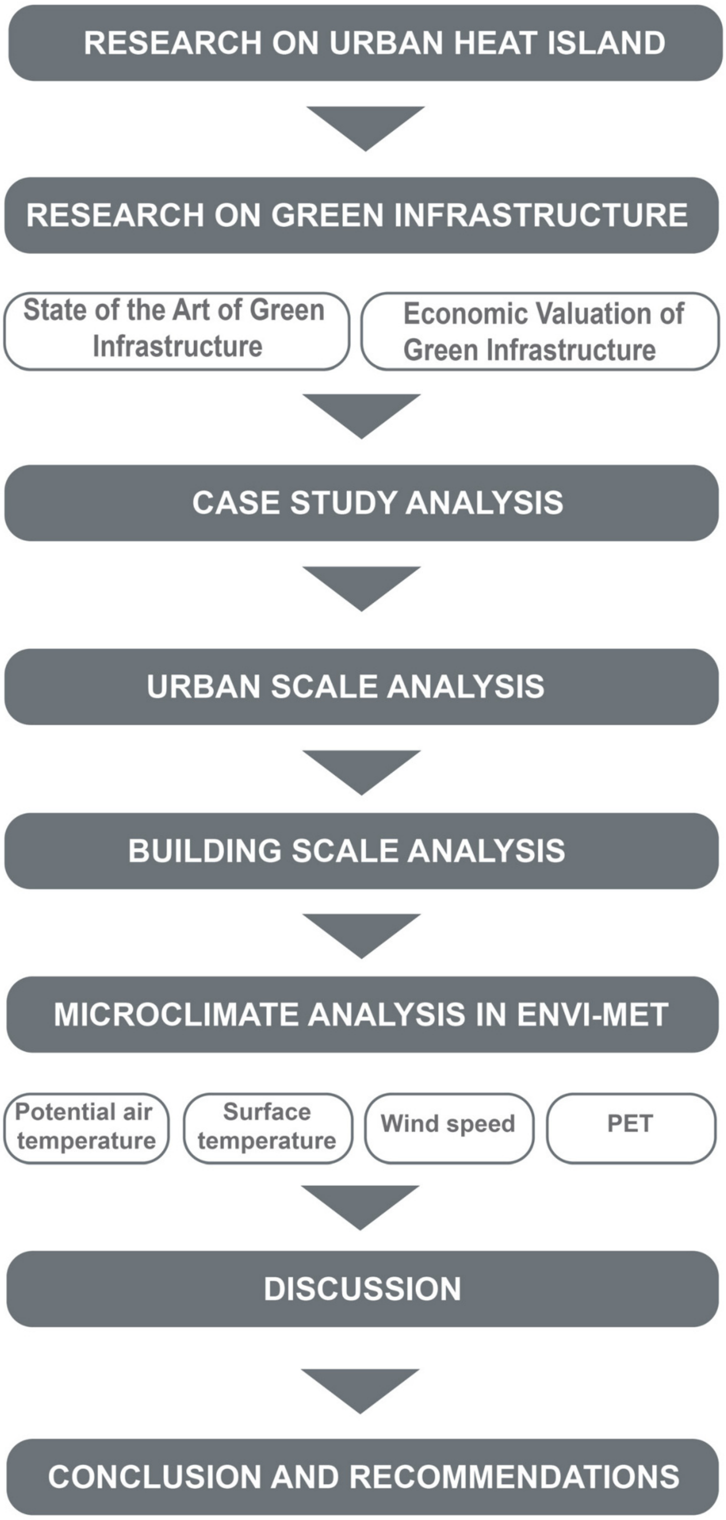


Figure 1: Methodology Scheme

CHAPTER 1
URBAN HEAT ISLAND (UHI)

1. Introduction

Urban areas worldwide are experiencing a significant environmental phenomenon known as the urban heat island (UHI) effect. The UHI effect refers to the phenomenon where urban areas exhibit higher temperatures compared to their surrounding rural areas (Oke, 1982). This temperature disparity arises due to the modification of land surfaces and the concentration of human activities in urban environments. UHI effect has become a growing concern for cities globally, as it poses numerous challenges to environmental sustainability, public health, energy consumption, and economic well-being.

1.1 Background

The UHI effect is primarily driven by several interconnected factors. Urban areas typically consist of impervious surfaces, such as asphalt and concrete, which absorb and retain heat during the day and release it at night, creating a thermal imbalance (Bowler et al., 2010). This process is known as the heat storage capacity of urban materials. Additionally, the replacement of vegetated areas with buildings and infrastructure reduces the amount of green space available for evaporative cooling and dirupts natural cooling processes (Taleghani et al., 2014). These changes in land cover and land use contribute to the altered microclimate within urban areas, resulting in elevated air and surface temperatures. The concentration of anthropogenic heat sources in urban areas also contributes to the intensification of the UHI effect. Activities such as energy generation, industrial processes, transportation, and human metabolism release excess heat into the urban environment (Akbari et al., 2016). These anthropogenic heat sources further exacerbate the temperature difference between urban and rural areas, particularly during heatwave events.

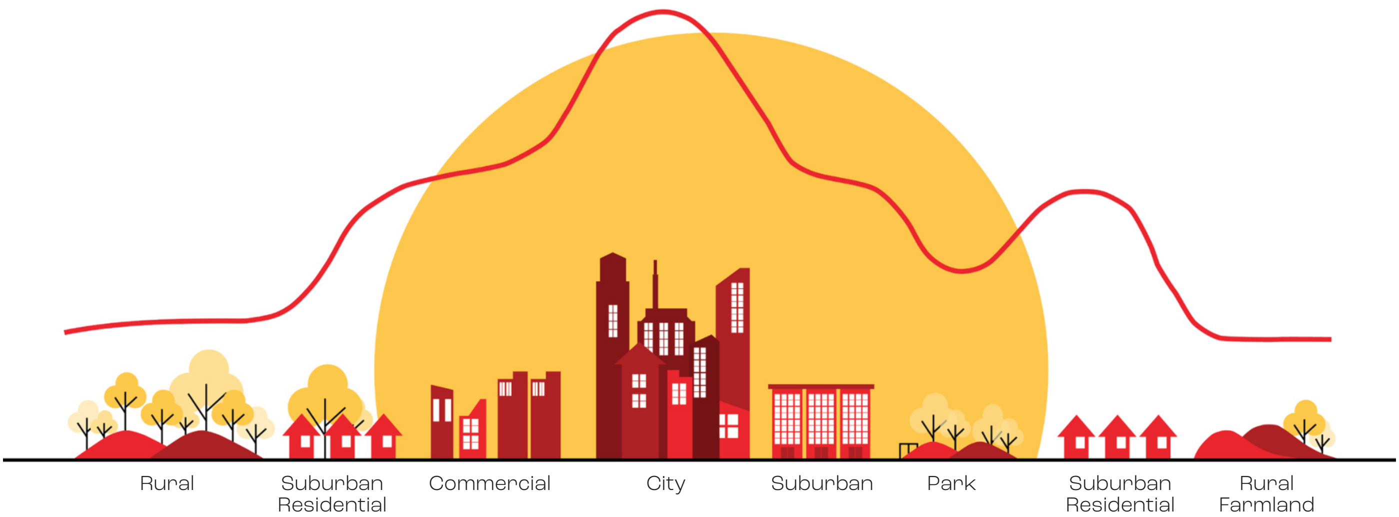


Figure 2: Urban heat island profile (redrawn by the author)
Source: https://blog.forumias.com/urban-heat-island-and-its-impact/

1.2 Significance

The UHI effect has profound implications for urban environments, public health, energy consumption, and the economy. Understanding its significance is crucial for addressing these challenges and implementing effective mitigation measures.

1.2.1 Environmental Sustainability

The UHI effect influences the microclimate within cities, altering thermal comfort and increasing the risk of heat-related illnesses among the urban population (Evola et al., 2017). It also exacerbates air pollution by enhancing the formation of pollutants such as ozone and particulate matter, which have adverse effects on human health and the environment (Kumar et al., 2019). Mitigating the UHI effect is crucial for creating sustainable and resilient cities that promote the well-being of their inhabitants.

1.2.2 Energy Consumption

The UHI effect contributes to increased energy demand for cooling in urban areas, leading to higher electricity consumption and greenhouse gas emissions (Saaroni et al., 2018). As urban populations continue to grow and the global climate warms, the demand for cooling systems will escalate, putting further pressure on energy infrastructure and exacerbating climate change. Mitigating the UHI effect can help reduce energy consumption and associated environmental impacts.

1.2.3 Urban Planning and Design

The UHI effect has implications for urban planning and design. It emphasizes the need for integrating green infrastructure, such as urban parks, green roofs, and trees, into the urban fabric (Zölch et al., 2016; Balany et al., 2020). These interventions can provide shade, facilitate evaporative cooling, improve air quality, and mitigate the UHI effect. By incorporating UHI mitigation strategies into urban planning and design, cities can create more sustainable, livable, and resilient environments.

1.2.4 Economic Considerations

The UHI effect also has economic implications. The implementation of UHI mitigation strategies requires financial investments. However, the long-term benefits, such as energy savings, improved public health, and enhanced livability, can outweigh the costs (Perini et al., 2013; Liu et al., 2016). Understanding the economic aspects of UHI mitigation is crucial for decision-makers and policymakers to prioritize and allocate resources effectively.

1.2.5 Equity and Social Justice

UHI effects tend to disproportionately impact disadvantaged communities, exacerbating existing social inequalities. Lower-income neighborhoods often lack adequate green spaces and face higher UHI intensities, leading to increased health risks for vulnerable populations (Laureti et al., 2018).

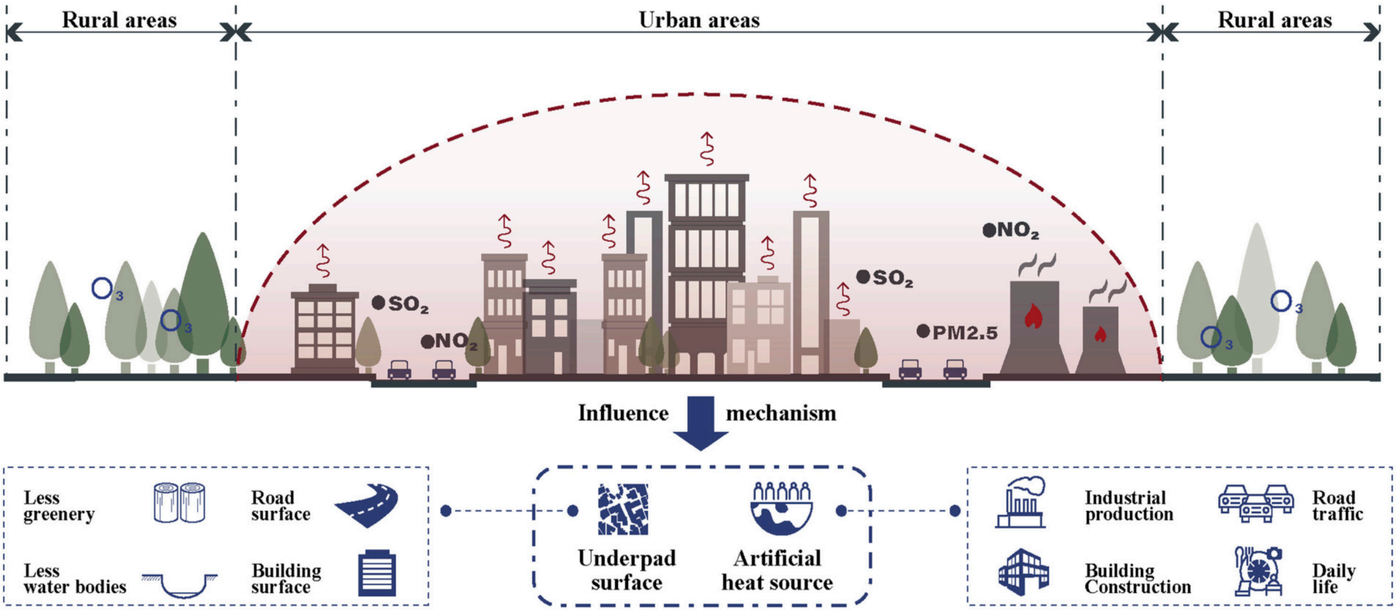


Figure 3: Urban heat island skemathic
Source: Yang M, Wang H, Yu CW, Cao S-J. A global challenge of accurately predicting building energy consumption under urban heat island effect. Indoor and Built Environment. 2023;32(3):455-459.

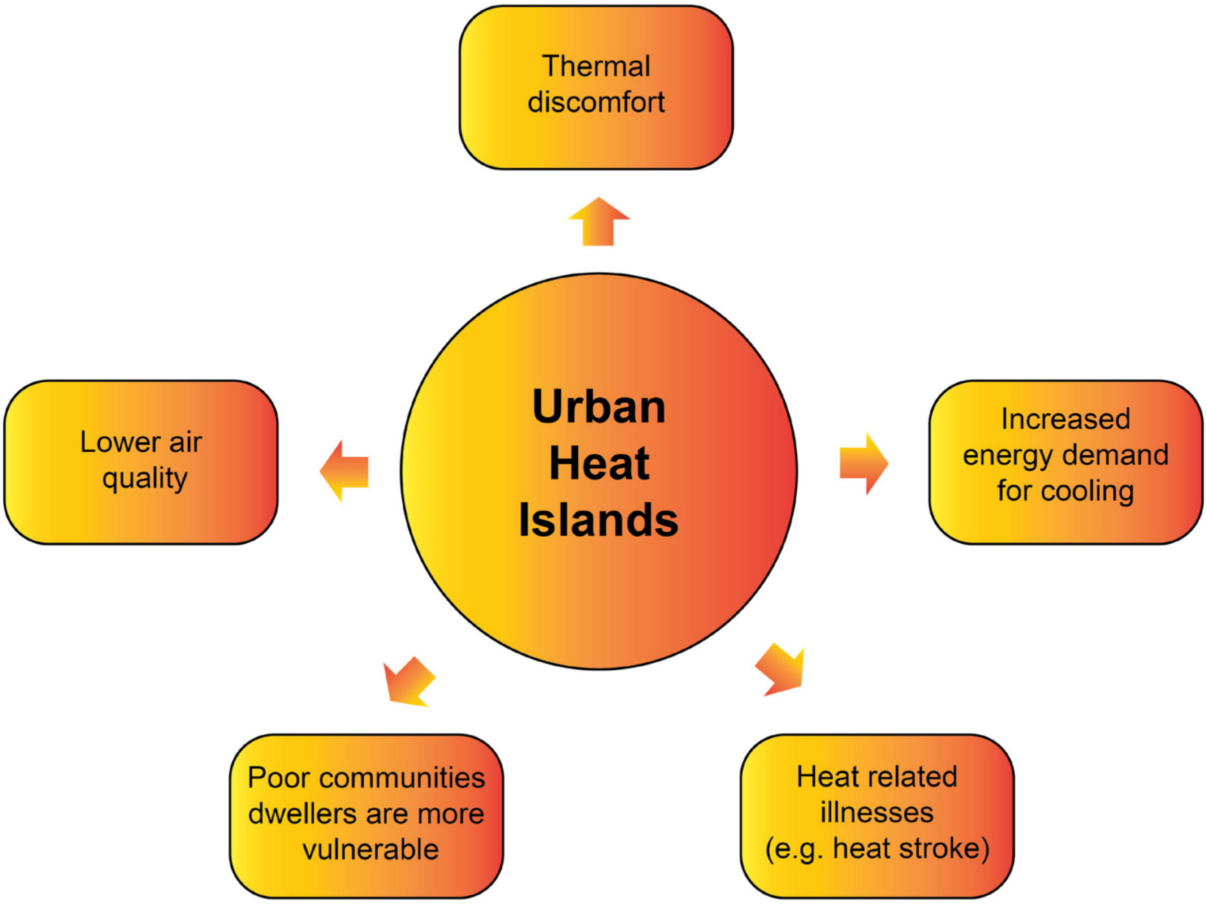


Figure 4: Impacts of Urban Heat Island
Source: developed by the author

1.3 Factors Contributing to Urban Heat Island Effect

Understanding the factors that contribute to the UHI effect is crucial for developing effective strategies to mitigate its impacts and create more sustainable and livable cities. This section provides a detailed overview of the key factors contributing to the UHI effect, drawing on the information provided in existing literatures.

1.3.1 Urban Form and Density

The physical characteristics of urban areas, including their form and density, significantly influence the UHI effect. Factors such as building height, arrangement, and materials impact the absorption, storage, and re-emission of solar radiation (Taleghani et al., 2014). Compact urban forms with high-rise buildings and dense street networks can lead to reduced airflow, limited shading, and the formation of urban canyons, which trap heat and exacerbate UHI intensity (Akbari et al., 2016).

1.3.1.1 Building Density and Configuration

High building density is a key characteristic of urban areas and has a direct impact on the UHI effect. Dense urban environments with closely spaced buildings create street canyons, where tall buildings form a barrier that restricts the movement of air and impedes natural ventilation (Chapman et al., 2017). This leads to reduced airflow and increased heat retention, exacerbating the UHI effect. Studies have shown that higher building densities contribute to elevated temperatures, particularly during the nighttime when radiative cooling is impeded (Oke, 1987). Therefore, urban planning strategies that promote lower building densities and more open spaces can help mitigate the UHI effect.

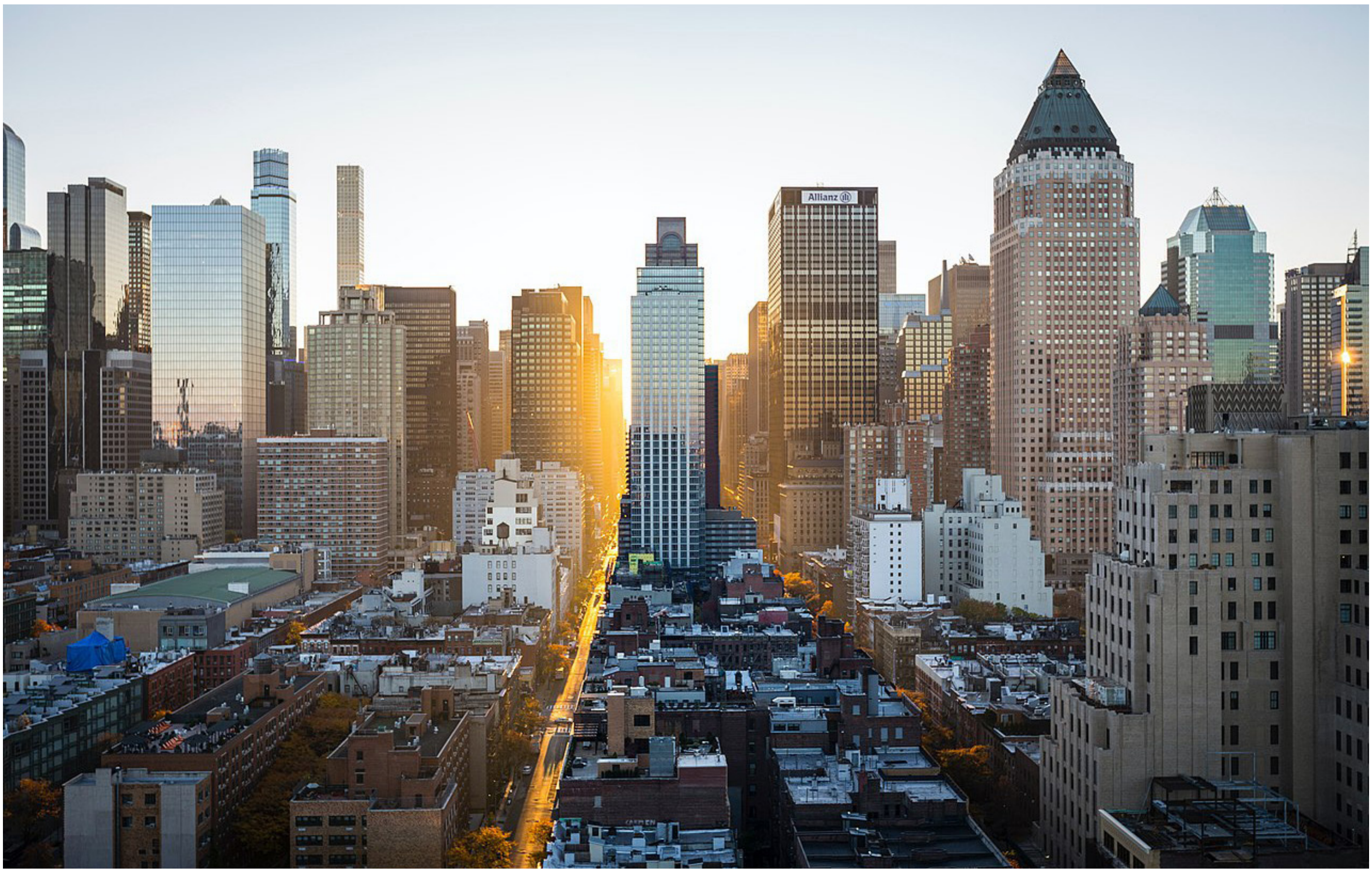


Figure 5: Example of dense urban living: High-rise buildings of Manhattan during sunset
https://en.wikipedia.org/wiki/Urban_heat_island#/media/File:High-rise_buildings_of_Manhattan_during_sunset.jpg

1.3.1.2 Street Geometry and Orientation

The layout and orientation of streets within urban areas influence the UHI effect. Narrow streets with tall buildings on both sides create street canyons that limit the penetration of solar radiation and airflow, resulting in higher temperatures (Arnfield, 2003). Street orientation also plays a role, as streets aligned in the east-west direction tend to receive more solar radiation, leading to increased heating (Lauwaet et al., 2018). Urban design approaches that incorporate wider streets, tree-lined boulevards, and strategic street orientation can enhance natural ventilation and reduce the UHI effect.

1.3.1.3 Building Height

The height of buildings influences the UHI effect by altering the urban surface energy balance. Tall buildings create larger vertical surfaces that absorb and re-radiate solar radiation, leading to increased heat accumulation (Grimmond, 2007). Moreover, taller buildings cast longer shadows, reducing the shading and cooling effects provided by neighboring structures. The combination of increased solar absorption and reduced shading from tall buildings contributes to higher surface temperatures in urban areas (Wang et al., 2013).

1.3.1.4 Impervious Surfaces

Urban areas often have a high percentage of impervious surfaces, such as concrete, asphalt, and rooftops, contributes to the UHI effect by altering the surface energy balance. These surfaces have low albedo and high thermal conductivity, resulting in increased absorption and re-radiation of solar radiation as heat (Imhoff et al., 2010). The lack of permeable surfaces also hinders water infiltration and reduces the cooling effect of evaporation. Strategies that promote the use of permeable pavements, green roofs, and cool roofs can help mitigate the UHI effect by reducing the proportion of impervious surfaces and enhancing surface reflectivity (Stewart and Oke, 2012).

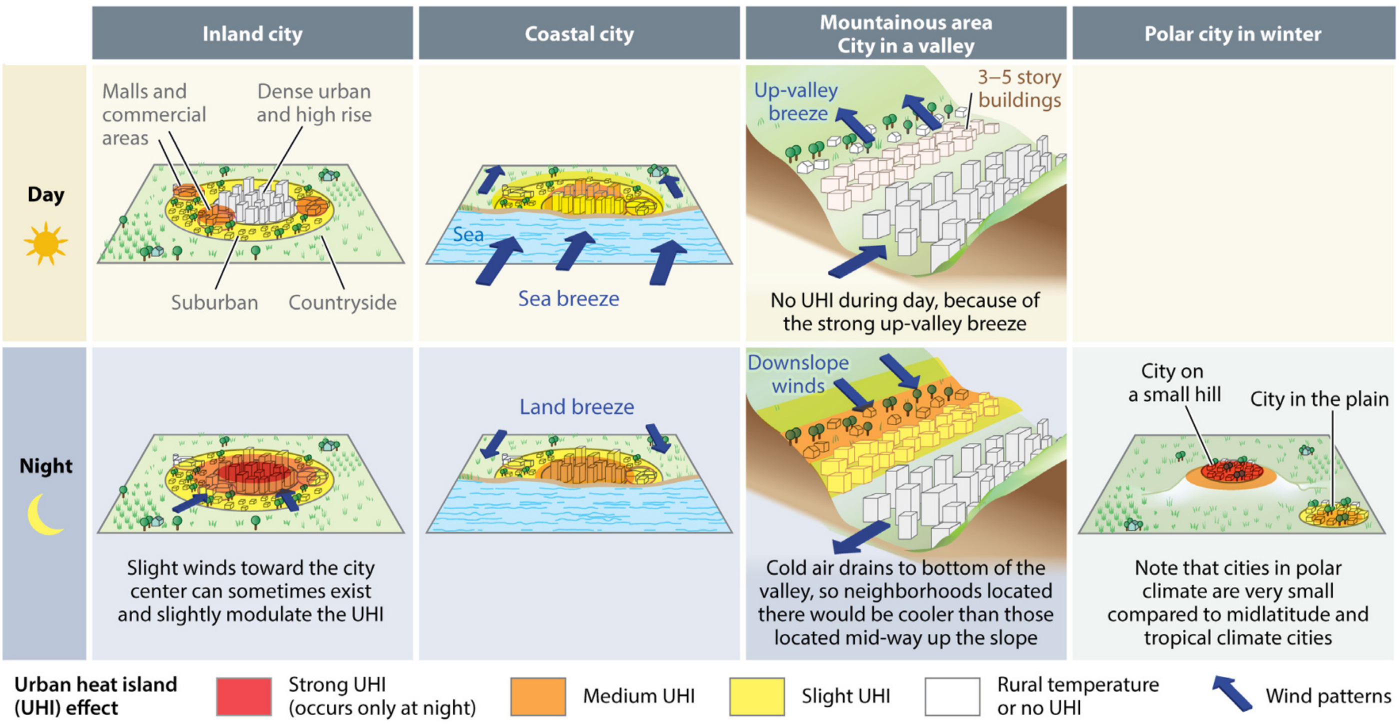


Figure 6: Cities often experiences stronger urban heat island effects at night; effects can vary with location and topography of metropolitan areas

Source: https://en.wikipedia.org/wiki/Urban_heat_island#/media/File:Urban_heat_island_variation.jpg

1.3.2 Anthropogenic Heat

Anthropogenic heat refers to the heat released by human activities, such as energy consumption, transportation, and industrial processes. These activities significantly contribute to the urban heat island (UHI) effect by adding heat to the urban environment. This section provides a detailed discussion on how anthropogenic heat acts as a contributing factor to the UHI effect.

1.3.2.1 Energy Consumption

The consumption of energy for various purposes, including heating, cooling, and electrical power, contributes to the release of waste heat in urban areas. Buildings, in particular, are major sources of anthropogenic heat due to the operation of heating, ventilation, and air conditioning (HVAC) systems (Chen et al., 2018). The excess heat generated by these systems, along with other energy-intensive processes, adds to the overall heat load in urban environments. Studies have shown a positive correlation between energy consumption and UHI intensity, highlighting the significant role of anthropogenic heat in urban temperature rise (Lauwaet et al., 2017).

1.3.2.2 Transportation

The transportation sector is another significant source of anthropogenic heat in urban areas. The combustion of fossil fuels in vehicles releases heat and exhaust gases, contributing to localized temperature increases. Traffic congestion, common in urban centers, exacerbates the release of anthropogenic heat as idling vehicles produce excess heat without much movement (Wang et al., 2020). The concentration of road networks, parking lots, and transportation infrastructure further intensifies the UHI effect. Efforts to reduce emissions, promote sustainable transportation options, and improve traffic flow can help mitigate the heat generated by transportation activities.

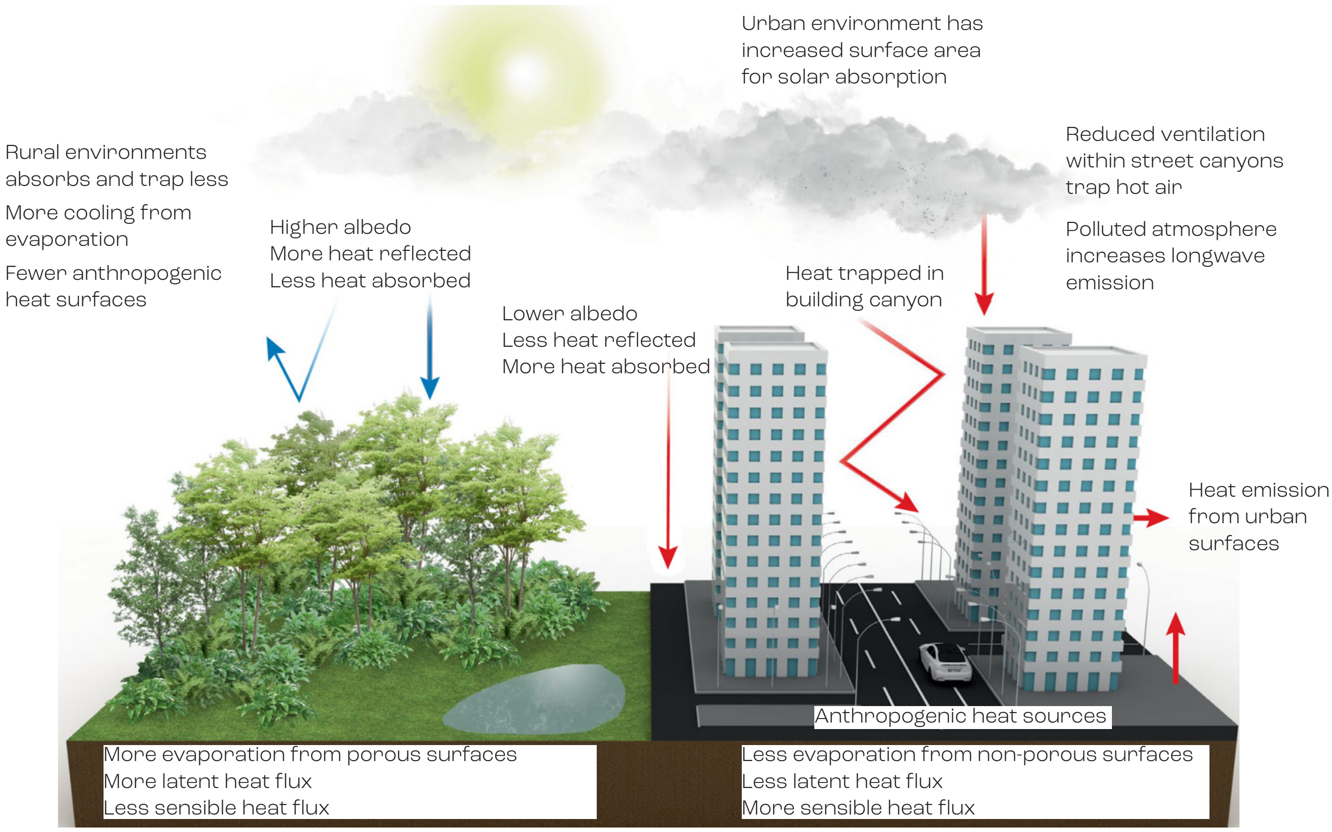


Figure 7: Urban heat island profile
Source: Wong et. al

1.3.2.3 Industrial Processes

Industrial activities, including manufacturing, power generation, and waste incineration, release substantial amounts of waste heat into the urban environment. Industrial facilities often have high-energy demands and operate continuously, leading to a significant contribution to anthropogenic heat. Additionally, industrial areas tend to have large expanses of impervious surfaces, such as concrete and metal, which absorb and re-radiate solar radiation as heat, further exacerbating the UHI effect (Li et al., 2019). Implementing energy-efficient technologies, waste heat recovery systems, and sustainable industrial practices can reduce the heat emissions associated with industrial processes.

1.3.2.4 Human Metabolism

The presence of a dense population in urban areas results in the release of anthropogenic heat through human metabolism. Human activities, such as walking, exercising, and even resting, generate heat that contributes to the local thermal environment (Stewart and Oke, 2012). The concentration of people in urban settings amplifies this effect, especially during periods of high population density and activity. The heat released by human metabolism can influence the microclimate of urban areas, contributing to higher temperatures and the UHI effect.

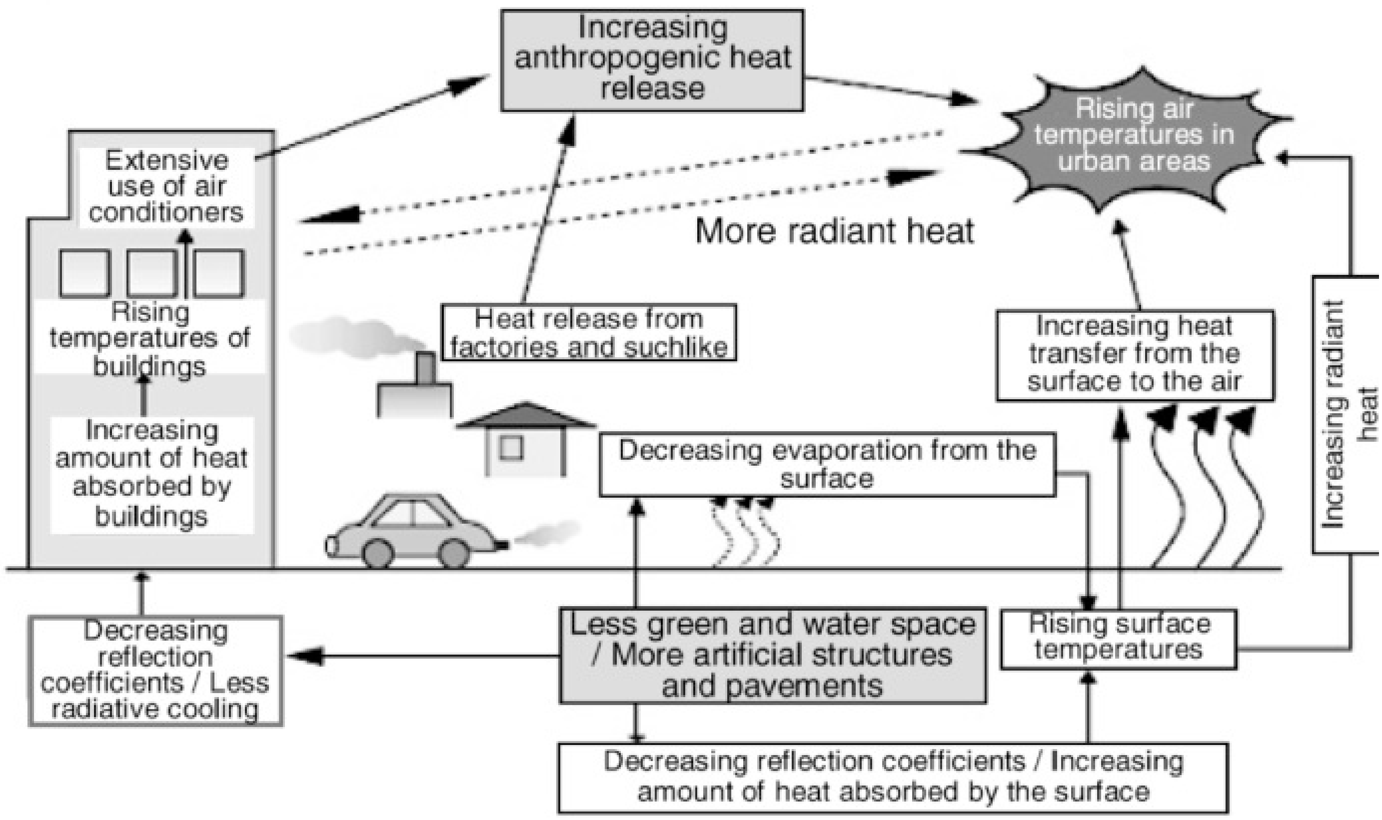


Figure 8: Causes of the urban heat island effect
source: Yamamoto (2016)

1.3.3 Surface Materials

Surface materials play a crucial role in influencing the urban heat island (UHI) effect. The type of materials used in urban areas, such as buildings, pavements, and roofs, significantly impact the absorption, reflection, and re-emission of solar radiation, thereby affecting local temperatures. This section provides a detailed discussion on how surface materials contribute to the UHI effect.

1.3.3.1 Albedo and Solar Radiation

Albedo, which refers to the reflectivity of a surface, plays a vital role in the UHI effect. Different surface materials have varying albedo values, influencing the amount of solar radiation absorbed or reflected. Dark-colored surfaces, such as asphalt and concrete, have low albedo and tend to absorb more solar radiation, converting it into heat (Akbari et al., 2009). These materials also inhibit evapotranspiration, reducing the cooling effect of vegetation and exacerbating heat buildup (Balany et al., 2020). In contrast, lighter-colored surfaces, such as reflective roofs or light-colored pavements, have higher albedo and reflect more sunlight, reducing heat absorption (Pomerantz et al., 2019). The prevalence of dark-colored surfaces in urban areas contributes to increased heat absorption, leading to higher UHI intensities.

1.3.3.2 Thermal Conductivity

The thermal conductivity of surface materials determines their ability to transfer and store heat. Materials with low thermal conductivity, such as certain types of insulation and green roofs, can help reduce heat transfer from the sun-exposed surfaces to the interior of buildings or the ground. This property prevents excessive heat accumulation and reduces the heat island effect (Emmanuel et al., 2013). In contrast, materials with high thermal conductivity, such as asphalt and concrete, tend to absorb and store heat, leading to elevated temperatures in urban areas.

Figure 9: Surfaces behaviour with solar radiation
Source: Developed by the author

NB: Surfaces with high albedo reflects 80% of incoming solar radiation, while those with low albedo reflects only 10%.

1.3.3.3 Heat Capacity

The heat capacity of surface materials affects their ability to store and release heat. Materials with high heat capacity, such as concrete and masonry, can absorb and store large amounts of heat during the day, releasing it slowly during the night (Wong et al., 2018). This delayed release of heat contributes to the persistence of high temperatures during nighttime, prolonging the UHI effect. In contrast, materials with low heat capacity, such as vegetation and green spaces, exhibit lower heat retention and faster cooling, helping to mitigate the UHI effect (Huang et al., 2018).

1.3.3.4 Urban Canyons

Surface materials also interact with urban canyon configurations, influencing the UHI effect. Urban canyons refer to street canyons formed by tall buildings on either side, which can trap heat and impede air circulation. The choice of surface materials within these canyons affects the amount of solar radiation absorbed and re-emitted, as well as the airflow patterns (Lee et al., 2019). Dark-colored surfaces, such as asphalt, can increase the absorption and re-emission of heat within urban canyons, exacerbating the UHI effect. Conversely, light-colored or reflective materials can help reduce heat absorption and enhance airflow, mitigating the UHI effect within urban canyons.

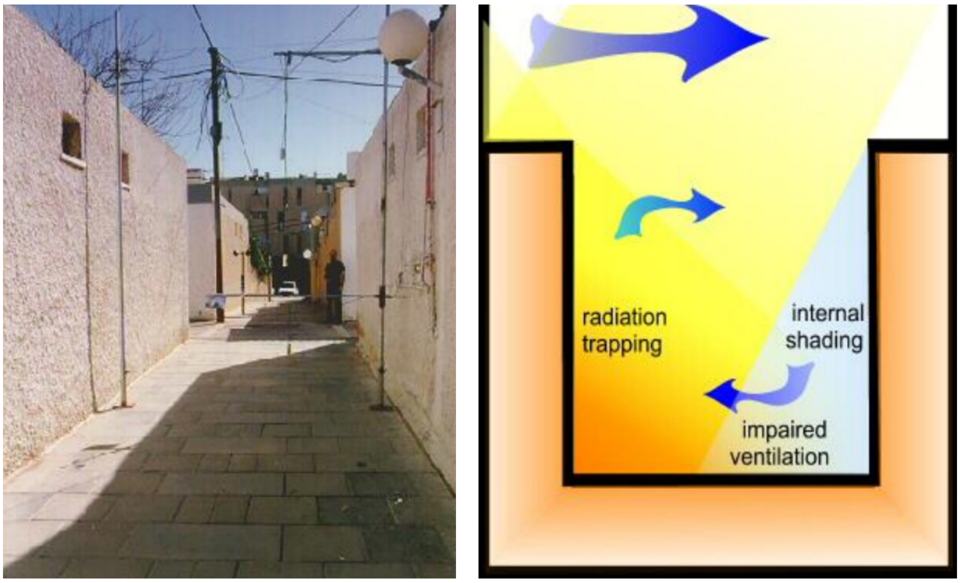


Figure 10: Formation of 'Urban Canyons' based on different heights and widths of urban masses, and their effect on the canyon temperature.
Source: https://www.teriin.org/sites/default/files/2018-03/urba-heat-island-effect-report.pdf

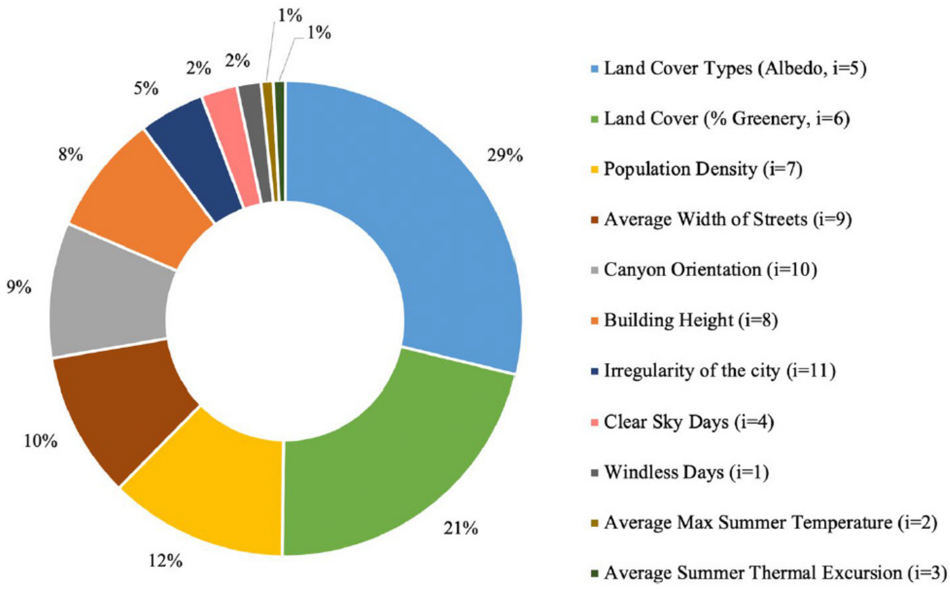


Figure 11: Influence of each parameter in the absolute max UHII phenomenon.
Source: Sangiorgio et a., 2020

1.3.4 Land Use and Land Cover Change

Land use and land cover change (LULCC) is a critical factor influencing the urban heat island (UHI) effect. The transformation of natural land covers into urbanized areas, including the conversion of vegetation to impervious surfaces, alters the energy balance and thermal characteristics of the urban environment. The expansion of built-up areas and the loss of vegetated surfaces disrupt natural cooling processes, alter airflow patterns, and reduce the availability of shading (Gill et al., 2007). Urbanization-induced land cover change not only increases UHI intensity but also impacts local climate, biodiversity, and ecological systems.

1.3.4.1 Urbanization and Urban Heat Island Intensity

Urbanization, characterized by the expansion of urban areas, is closely associated with the UHI effect. The rapid increase in buildings, infrastructure, and human activities alters the surface characteristics and energy balance of the urban environment. Urban areas tend to have higher population density, increased impervious surface coverage, and reduced vegetation cover, all of which contribute to elevated temperatures (Oke, 1982). Studies have shown a positive correlation between the degree of urbanization and the intensity of the UHI effect (Akbari et al., 2009; Santamouris et al., 2015).

1.3.4.2 Loss of Vegetation

The conversion of natural land cover, such as forests or grasslands, into impervious surfaces, such as concrete or asphalt, has a profound impact on surface temperature. Impervious surfaces have lower evaporative cooling potential and higher heat storage capacity compared to natural vegetation (Grimmond, 2007). The loss of vegetation leads to a decrease in evapotranspiration, which is the combined process of water evaporation from surfaces and transpiration from plants. Evapotranspiration plays a crucial role in cooling the environment by absorbing and dissipating heat through the process of evaporation (Oke, 1982). Consequently, the replacement of vegetated areas with impervious surfaces reduces the cooling effect provided by evapotranspiration and increases heat retention, leading to higher temperatures in urban areas.

1.3.4.3 Urban Heat Island Spatial Patterns

The spatial distribution of land use and land cover types within urban areas also influences the UHI effect. Variations in land use patterns, such as the arrangement of green spaces, buildings, and water bodies, can result in spatially heterogeneous temperature distributions. For example, areas with high building density and low vegetation cover tend to exhibit higher temperatures, while areas with more green spaces and water bodies may experience lower temperatures (Seto and Shepherd, 2009). These variations in land use patterns contribute to the formation of UHI hotspots and can help identify strategies for targeted mitigation measures.

1.3.4.4 Climate Change Interactions

It is important to consider the interactions between Land use and land cover change (LULCC) and climate change in the context of the UHI effect. Climate change impacts, such as rising temperatures and changing precipitation patterns, can influence land use decisions and exacerbate the UHI effect. Conversely, the UHI effect can also amplify the effects of climate change at the local scale. Understanding these interactions is crucial for developing effective mitigation and adaptation strategies that consider both LULCC and climate change factors (Streutker, 2003).

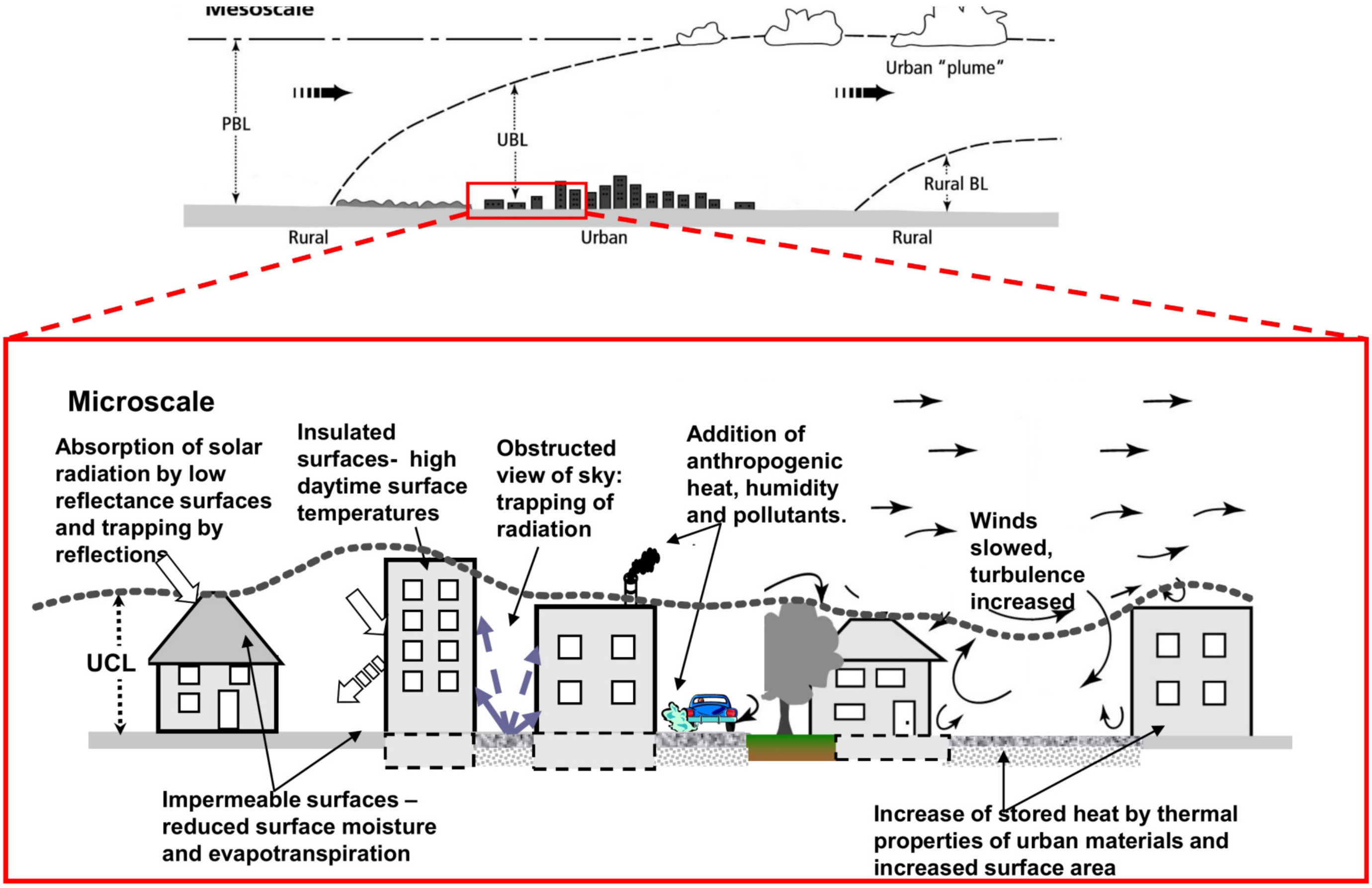


Figure 12: Urban Heat Island Process
Source: https://www.canada.ca/content/dam/hc-sc/images/services/health/publications/healthy-living/reducing-urban-heat-islands-protect-health-canada/UHI-Guide-Figure-2-EN.jpg

CHAPTER 2
GREEN INFRASTRUCTURE (GI)

2.1 Definition and Origins of Green Infrastructure (GI)

Green infrastructure refers to a network of interconnected natural and semi-natural spaces, including parks, forests, wetlands, green roofs, green walls, urban gardens, and street trees, that are strategically planned, designed, and managed to deliver a wide range of environmental, social, and economic benefits to urban areas (Gill et al., 2007; Beauchamp and Adamowski, 2012; Wang and Banzhaf, 2018). It is a nature-based approach that aims to mimic or restore natural ecosystems within urban settings, providing multiple ecosystem services and promoting sustainable urban development.

The origins of green infrastructure can be traced back to the field of landscape planning and urban design, which recognized the importance of incorporating natural elements into urban spaces for their aesthetic, environmental, and social benefits. The term "green infrastructure" was first coined in the late 1990s by the U.S. Environmental Protection Agency (EPA) to describe the interconnected network of green spaces and natural areas that can provide ecological services and contribute to sustainable communities (Gill et al., 2007; Wang and Banzhaf, 2018). Since then, the concept of green infrastructure has evolved and gained recognition at the international level, with various definitions and frameworks proposed by researchers, practitioners, and policymakers. For example, the European Union (EU) defines green infrastructure as "a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission, 2013).

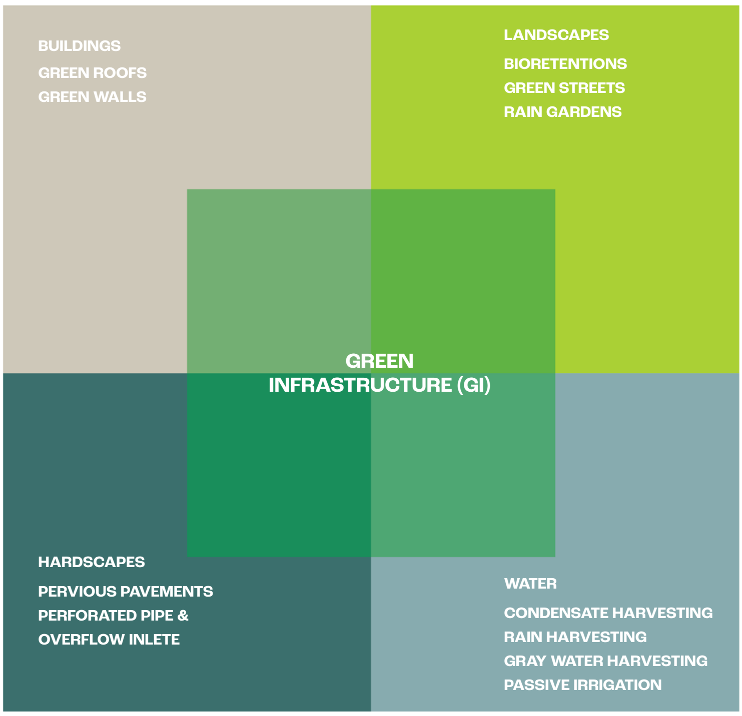


Figure 14: Green infrastructure overview (redrawn by the Author)
Source: https://www.klausinggroup.com/blog/what-is-green-infrastructure

The concept of green infrastructure has evolved to encompass broader notions, such as nature-based solutions and ecosystem services. Nature-based solutions emphasize the integration of green infrastructure within a broader framework that aims to address societal challenges by harnessing the benefits of nature (Saaroni et al., 2018). Ecosystem services provide a framework for understanding and valuing the tangible and intangible benefits that ecosystems, including green infrastructure, provide to society (Ersoy Mirici, 2022).

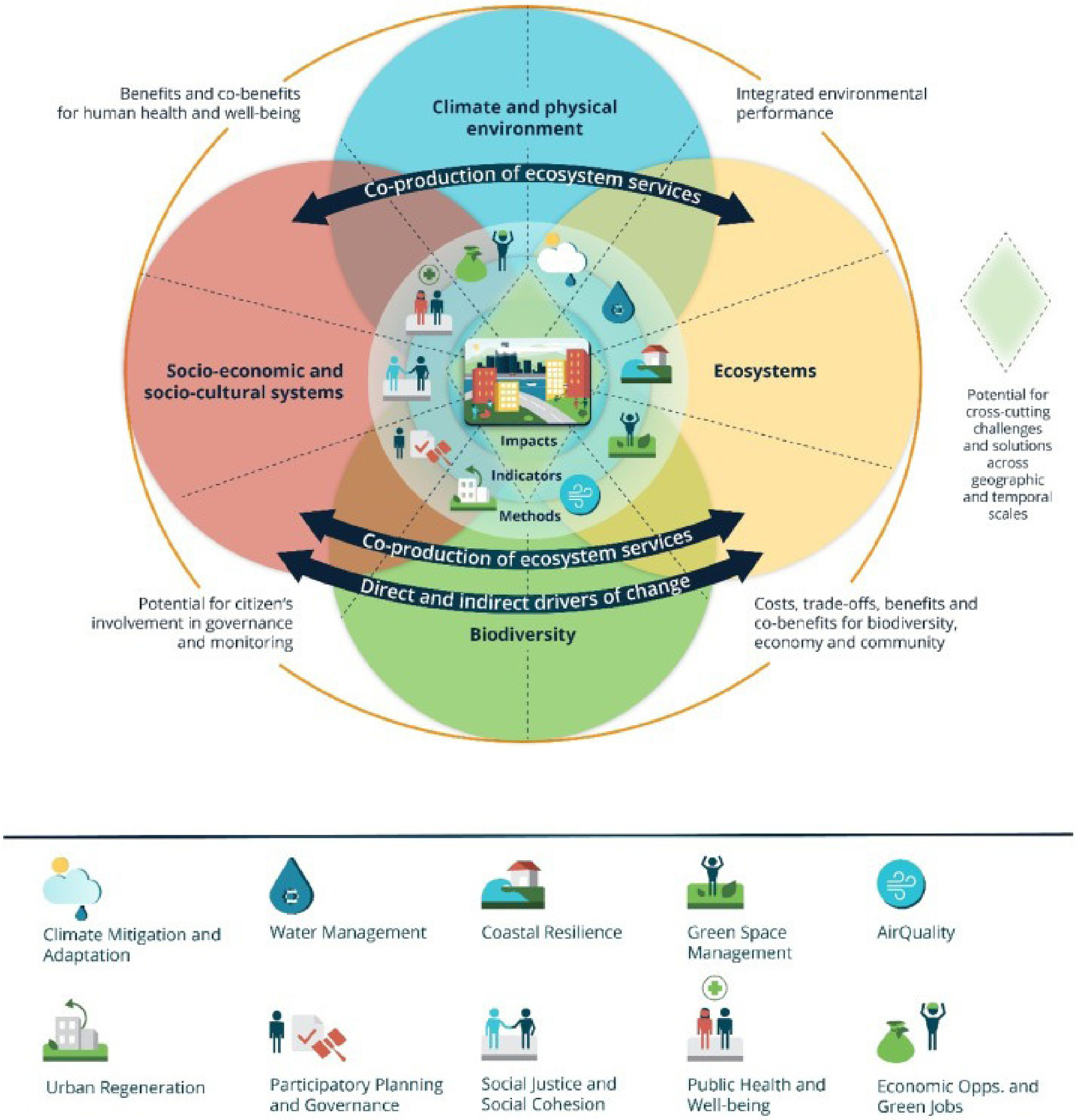
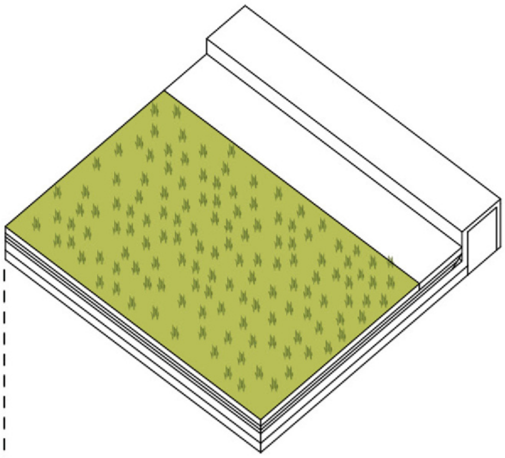


Figure 15: The NBS assessment framework considering different elements of the system, the 10 challenge areas and indicators and methods for assessing NBS impacts within and across challenge areas.

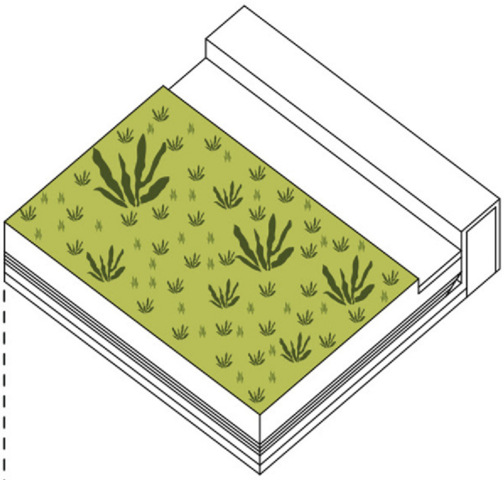
Source: Raymond et al., 2017



Extensive green roof
Building Solutions

Approach: Designs of building with green roof or apply on existing ones.

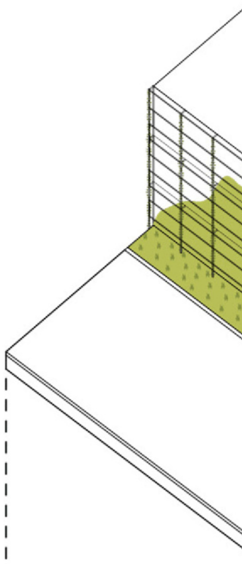
- Water management and filteration
- Insulation and cooling
- Feasibility to include social interactions, and recreation



Intensive green roof
Building Solutions

Approach: Design of buildings with green roof or apply on existing ones.

- Ability to carry a wide range of species
Water management and filteration
- Insulation and cooling
- Attracting the biodiversity
- Feasibility to include social interactions, and recreation
- Urban Farming
- Possible integration of educational activities in form of a classroom or Even specilized LABs



Ground-base
Building Soluti

Approach: Des
green facade c
ones.

- Shading provisio
- Mitigation of
enhances the oc
- Aesthetic suppo
design
- A suitable solu
climbing and
which can gro
building envelop
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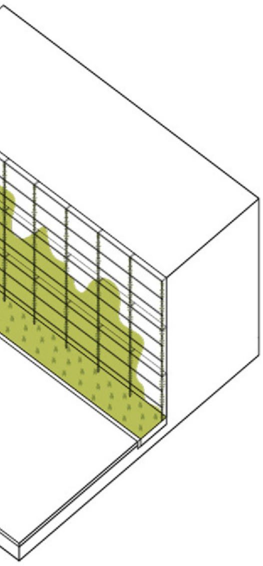
Figure 16: The contribution and implementation approaches of suitable NBS
Source: Khachatourian Saradehi, L., & Khachatourian Saradehi, A. 2022. Nature-Based Solutions For Urban Adaptivity: Regenerating Former OSI-GHIA Industrial Site. Doctoral dissertation, Politecnico di Torino.



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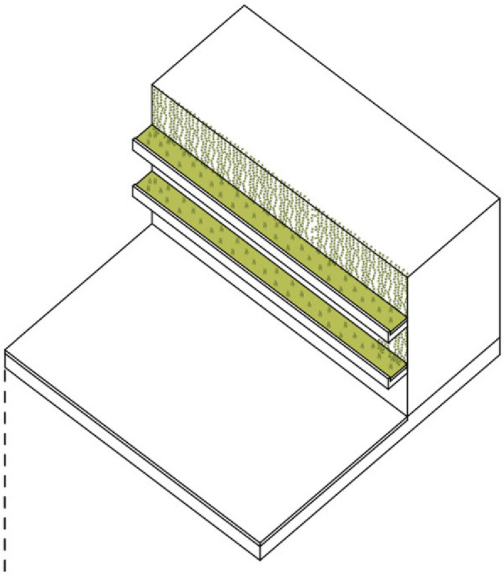
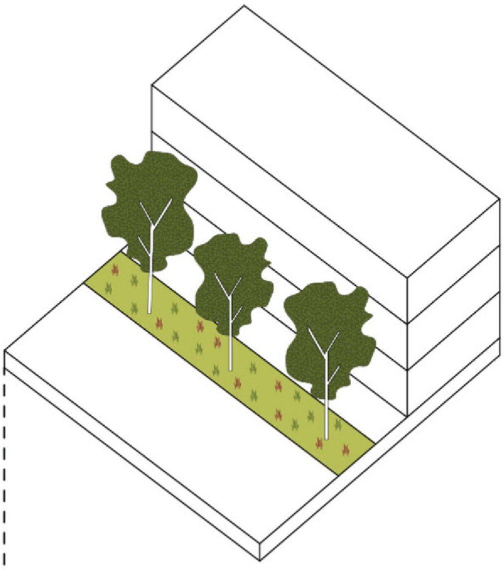


Facade-bounded greening
Building Solutions

Approach: Design of buildings with green facade or apply on existing ones.

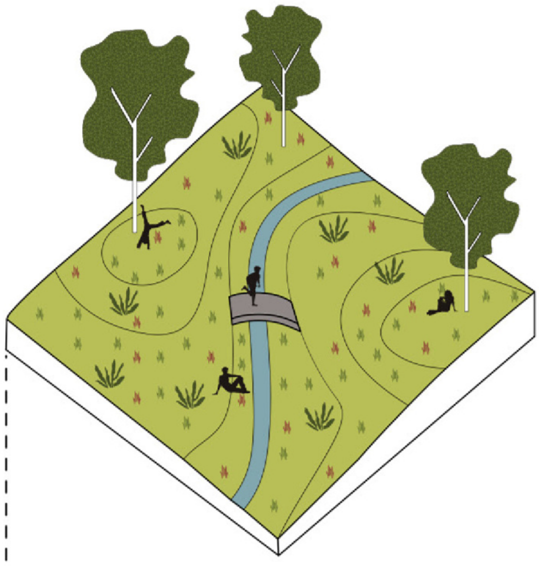
- Shading provision for the facade
- Mitigation of Air pollution which enhances the occupants' health
- Aesthetic support to the architectural design
- A suitable solution to provide a diverse mix of plants in the vertical direction
- Decreasing the overall load of the green wall due to the implemented substrates on the facade



Street tree canopies
Green Corridors

Approach: Conserving the exisiting drainage network and trees. Combine the components of existing green infrastructures, develop them as a linked network, extending in city.

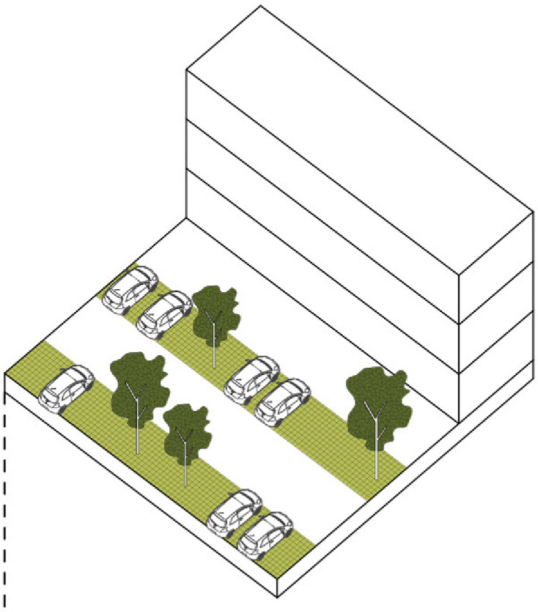
- Shading provision for the streets which reduces the tempreture of air and surrounding surface
- Cool paths absorb people creating opportunities for social interactions, shops and services
- Certain tree species are attractive for visitors



Natural playgrounds
Open Green Spaces

Approach: Protect and renovate the actual green space. Temporary utilization of undefined areas as open green space along with designing new ones.

- A key supporter of social interactions and sports activities
- Presence of natural elements such as plants, flowers, rocks and water surfaces, enhance creativity and the ability to appreciate and perceive nature among children
- A potential venue to conduct educational and cultural activities as well as the recreation
- Coping strategy for the stormwater challenges



Permeable pavements
Bioretention Areas

Approach: Improve entire drainage system on the street border edges and designate green strips all along the street.

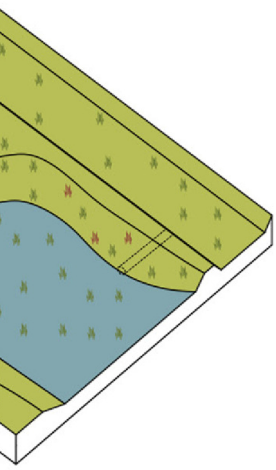
- Their water storage capacity treats and copes with runoff the rainwater, by absorbing transefring the water to their reservoir layer underneeth
- Integratable both on the urban and building scales

Retention por
Bioretention Ar

Approach: Im
drainage syste
bioretention area

- Deep areas to
stormwater dur
having the capac
by water
- The water level
pond's capacity
discharged to the
- Ponds could be
applicable fur
playgrounds bec
water decreases
heavy rains

Figure 17: The contribution and implementation approaches of suitable NBS
Source: Khachatourian Saradehi, L., & Khachatourian Saradehi, A. 2022. Nature-Based Solutions For Urban Adaptivity: Regenerating Former OSI-GHIA Industrial Site. Doctoral dissertation, Politecnico di Torino.



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city to be totally filled

doesn't exceed the
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combined with other
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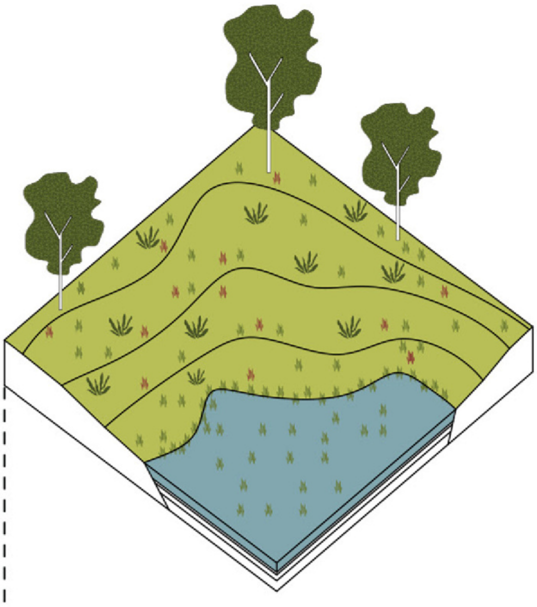
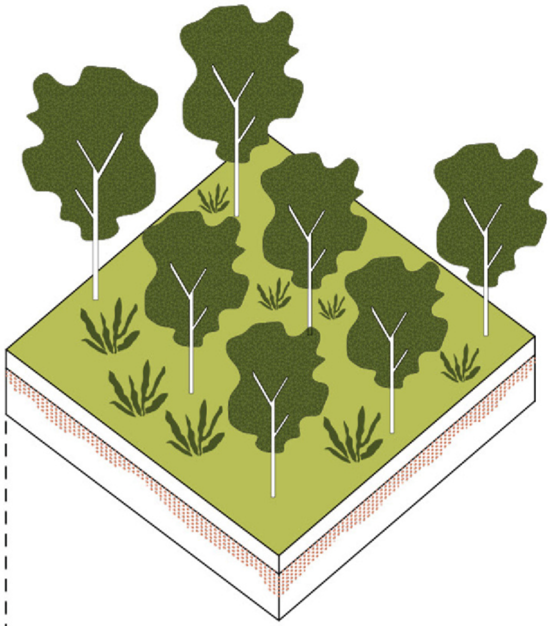


Surface constructed wetlands
Constructed Wetlands

Approach: Transforming the actual green spaces to wetlands in case it's a solution to a site-specific challenge or construct a new one.

- Attracting the biodiversity
- Filtering water by cleaning it from contaminants through vegetation planted on the Incrementally decreasing slope into the soil
- Properly designed wetlands are efficient for Carbon storage and sequestration



Phytoremediation forest
Urban Forests

Approach: Plant in contaminated areas to remediate the contaminants and restore usable spaces.

- Combination of the plants with specific feature of absorbing contaminant from the soil is a key strategy especially for the abandoned industrial areas with the presence of heavy metals in the soil
- A well-organized phyto-management would be fruitful with economic revenues

2.2 Theoretical Framework of Green Infrastructure

Green infrastructure is a concept that encompasses the integration of natural and semi-natural features into urban environments to provide multiple benefits. To understand and analyze the concept of green infrastructure, several theoretical frameworks have been proposed. These frameworks provide a structured approach to examine the ecological, social, and economic dimensions of green infrastructure planning, implementation, and management.
The following theoretical framework presents key elements and concepts that contribute to the understanding of green infrastructure.

2.2.1 Ecosystem Services Framework

The ecosystem services framework offers a valuable lens to understand the benefits provided by green infrastructure. It recognizes that green infrastructure functions as ecological systems, delivering a wide range of services that contribute to human well-being (Belčáková et al., 2019). Ecosystem services include provisioning services (e.g., food, water), regulating services (e.g., climate regulation, water purification), cultural services (e.g., recreational opportunities, and supporting services (e.g., biodiversity maintenance) (Millennium Ecosystem Assessment, 2005). This framework enables the identification, assessment, and valuation of the diverse ecosystem services that green infrastructure provides.

Figure 18: A range of services naturally supplied by ecosystems.
Source: ihttps://www.visionlearning.com/en/library/Biology/2/Environmental-Services-and-Economics/279

2.2.2 Landscape Ecology Framework

The landscape ecology framework emphasizes the connectivity and spatial arrangement of green infrastructure elements across the urban landscape (Bowler et al., 2010). It considers the interactions between different patches of green spaces, such as parks, urban forests, and wetlands, and their ecological functions. This framework recognizes the importance of creating a network of green spaces to support biodiversity, facilitate ecological processes, and enhance ecosystem resilience. Landscape metrics, such as patch size, connectivity, and configuration, are utilized to analyze the spatial structure and functioning of green infrastructure (Zölch et al., 2016).

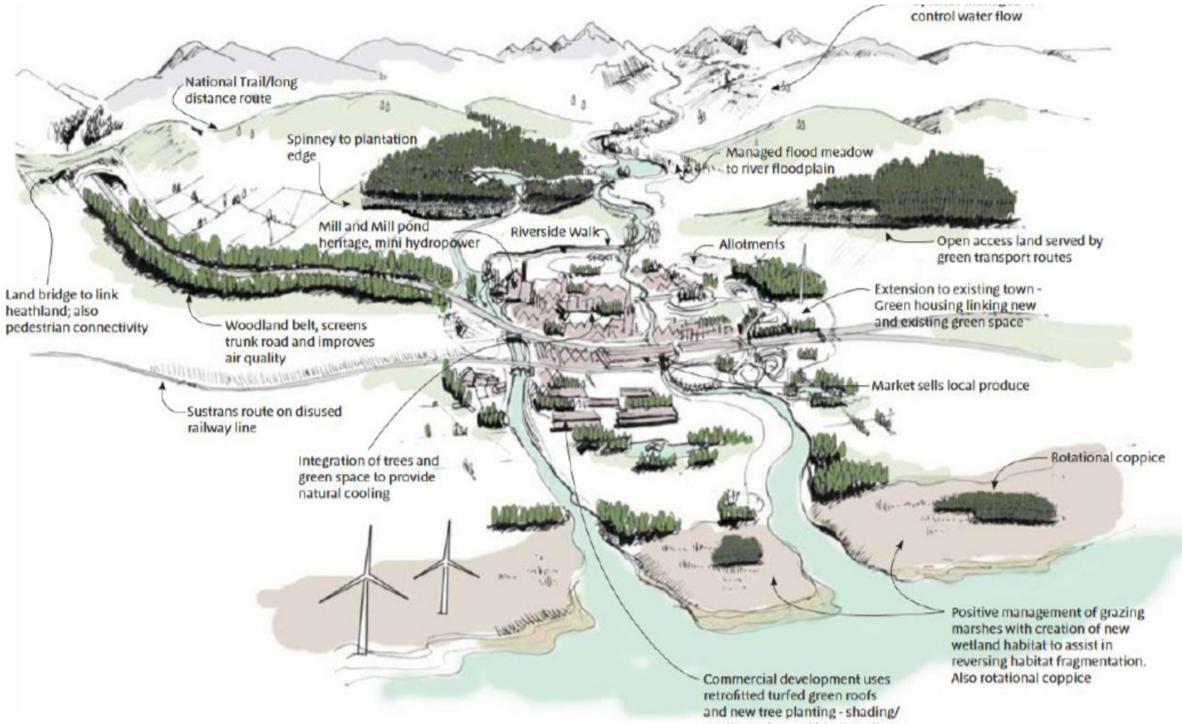


Figure 19: Green Infrastructure, Multifunctionality and Place-making - Example 1
Source: Natural England 2009, p. 26

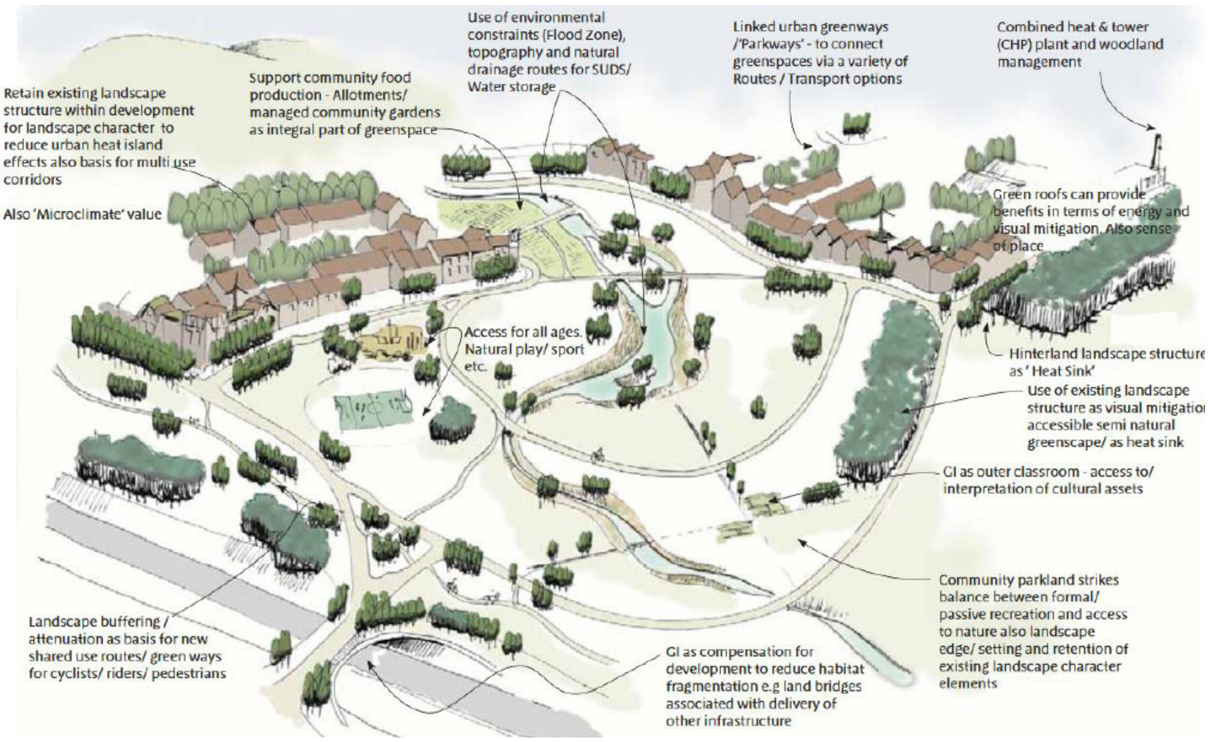


Figure 20: Green Infrastructure, Multifunctionality and Place-making - Example 2
Source: Natural England 2009, p. 26

2.2.3. Socio-Ecological Systems Framework

The socio-ecological systems framework highlights the interconnectedness between social and ecological systems within the context of green infrastructure planning and management (Ersoy Mirici, 2022). It recognizes that green infrastructure is not solely about ecological processes but also about human interactions, values, and behaviors. This framework integrates social, economic, and institutional dimensions, acknowledging the role of stakeholders, governance structures, and decision-making processes in shaping green infrastructure outcomes. It emphasizes the importance of participatory approaches, collaboration, and adaptive management to achieve sustainable and equitable green infrastructure (Laureti et al., 2018).

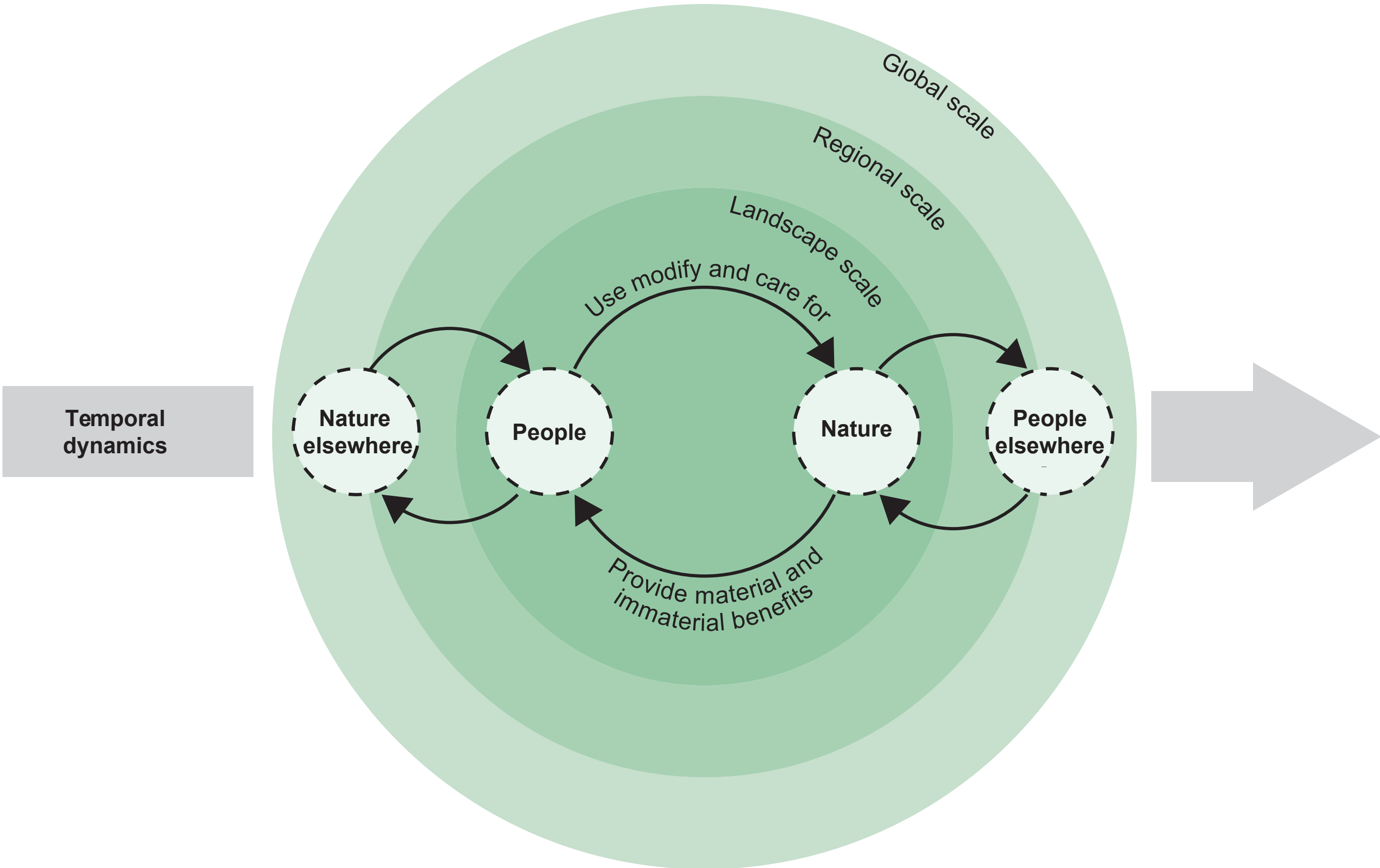


Figure 21: Current Opinion in Environmental sustainability
Source: https://api.semanticscholar.org/CorpusID:18737183

2.2.4 Resilience Framework

The resilience framework focuses on the capacity of green infrastructure to absorb disturbances, adapt to change, and maintain essential functions and services (Phelan et al., 2015). It acknowledges that urban environments are subject to various shocks and stresses, such as climate change, urbanization, and natural disasters. The resilience framework emphasizes the need to design and manage green infrastructure to enhance the resilience of urban systems and communities. It considers aspects such as redundancy, diversity, and adaptive capacity to promote the ability of green infrastructure to withstand and recover from disturbances (Colding et al., 2015).

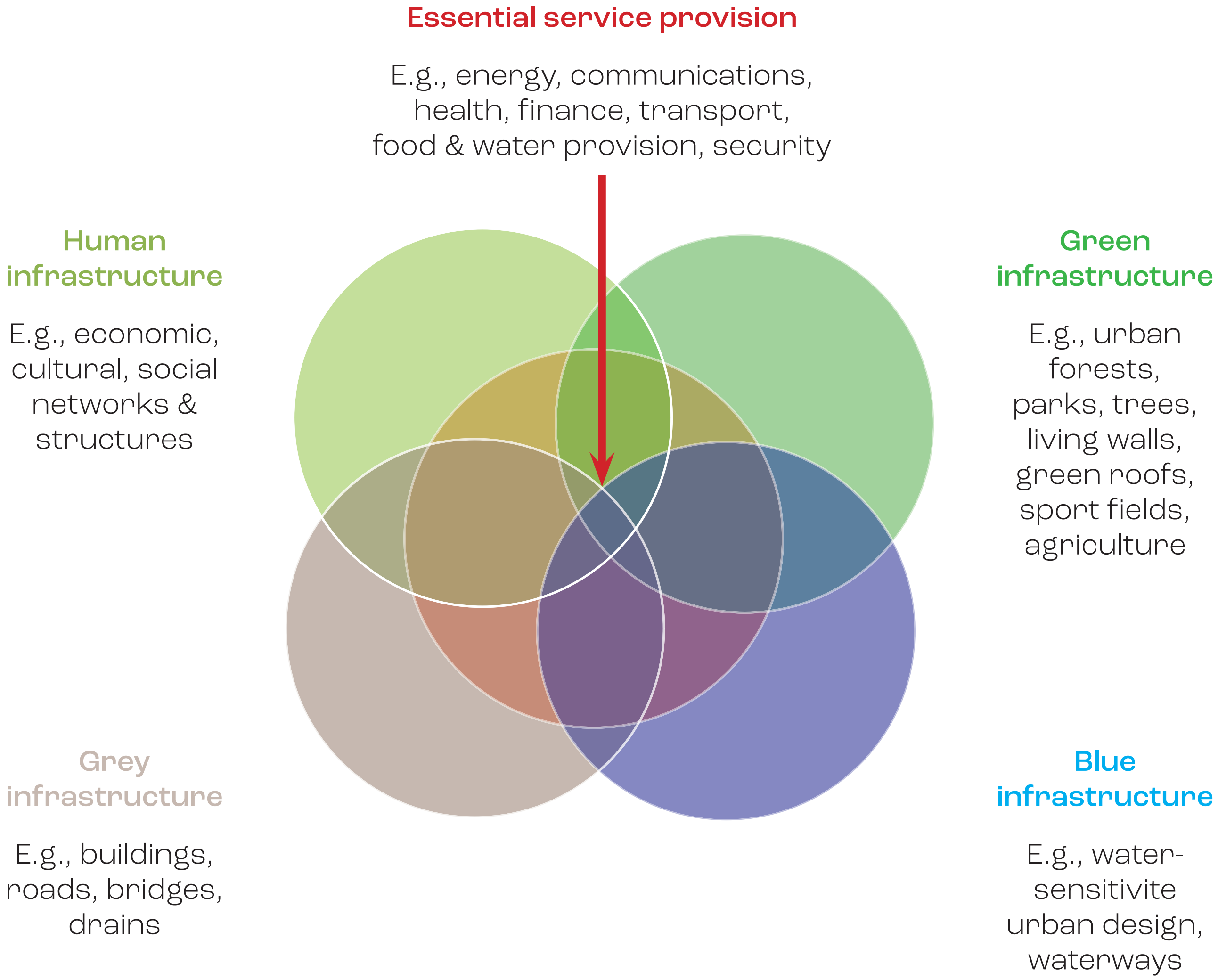


Figure 22: Current Opinion in Environmental sustainability
Source: https://www.visionlearning.com/en/library/Biology/2/Environmental-Services-and-Economics/279

2.2.5 Stakeholder Engagement and Collaboration

Successful green infrastructure planning and implementation require active stakeholder engagement and collaboration. Engaging diverse stakeholders, including local communities, governmental agencies, non-governmental organizations, and private entities, fosters participatory decision-making processes and promotes ownership and support for green infrastructure projects (Colding et al., 2013). Collaboration among stakeholders also facilitates knowledge sharing, resource pooling, and the development of shared goals and strategies.

2.2.6 Policy and Governance

Green infrastructure is influenced by policy and governance frameworks at different scales. Policy measures, such as land use planning regulations, green space standards, and incentives for green infrastructure development, can shape the implementation and effectiveness of green infrastructure (Haase et al., 2014). Effective governance structures, including coordination mechanisms, institutional arrangements, and financing mechanisms, are crucial for the successful integration of green infrastructure into urban planning and management.

Figure 23: Citizen involvement in the SUMP process

Source: https://www.visionlearning.com/en/library/Biology/2/Environmental-Services-and-Economics/279

2.3 Typologies of Green Infrastructure

Green infrastructure encompasses a diverse range of natural and semi-natural features integrated into the built environment to provide multiple benefits. To categorize and classify the different elements and functions of green infrastructure, various typologies have been proposed. These typologies help in understanding the diverse components of green infrastructure and guide its planning, design, and management. Here, we explore some of the key typologies of green infrastructure based on the provided bibliographical references.

2.3.1 European Commission Typology

The European Commission has developed a typology that distinguishes between different types of green infrastructure elements based on their characteristics and functions (Naumann et al., 2011). This typology includes three main categories:

2.3.1.1 Green Spaces: This category encompasses traditional parks, gardens, and urban green areas. Green spaces provide recreational opportunities, enhance biodiversity, and contribute to the overall aesthetic quality of urban environments.

2.3.1.2 Blue Spaces: Blue spaces refer to water bodies such as rivers, lakes, ponds, and wetlands. They play a crucial role in water management, habitat creation, and enhancing the overall ecological resilience of urban areas.

2.3.1.3 Grey-Green Spaces: Grey-green spaces include features like green roofs, green walls, and permeable pavements that are integrated into the built environment. These features provide stormwater management, reduce heat island effects, and enhance biodiversity within urban settings.

Figure 24: EU Commission definition
Source: https://www.visionlearning.com/en/library/Biology/2/Environmental-Services-and-Economics/279

2.3.2 Functional Typology

Another approach to typifying green infrastructure is through a functional perspective, which classifies elements based on their specific ecological functions and services (Benedict & McMahon, 2006). This typology highlights the ecosystem services provided by different components of green infrastructure, such as:

2.3.2.1 Climate Regulation: Features like urban forests, green roofs, and green walls help regulate local temperatures, reduce heat island effects, and mitigate climate change impacts.

2.3.2.2 Water Management: Wetlands, permeable pavements, and bioswales contribute to stormwater management, groundwater recharge, and flood prevention by absorbing and retaining water.

2.3.2.3 Biodiversity Enhancement: Parks, gardens, urban forests, and green corridors provide habitats and connectivity for various species, promoting biodiversity conservation and ecological resilience.

2.3.2.4 Recreational and Cultural Services: Parks, urban gardens, and green open spaces offer opportunities for recreation, leisure, and cultural activities, improving the quality of life for urban residents.

2.3.3 Spatial Typology

A spatial typology of green infrastructure focuses on the arrangement and distribution of green elements within urban areas (Ahern, 1995). This typology classifies green infrastructure based on its spatial characteristics:

2.3.3.1 Core Areas: Core areas comprise large contiguous patches of green spaces, such as urban forests or nature reserves, which serve as key biodiversity hotspots and provide recreational opportunities.

2.3.3.2 Networks and Corridors: Green corridors and networks connect core areas and provide connectivity for wildlife movement, enhance urban biodiversity, and facilitate ecological processes.

2.3.3.3 Localized Green Spaces: Localized green spaces include smaller parks, gardens, and green spaces distributed throughout urban neighborhoods, providing recreational amenities and improving microclimates.

2.3.3.4 Greening of Buildings: This category includes features like green roofs, green walls, and vertical gardens integrated into buildings, contributing to urban greening and reducing the ecological footprint of built structures.

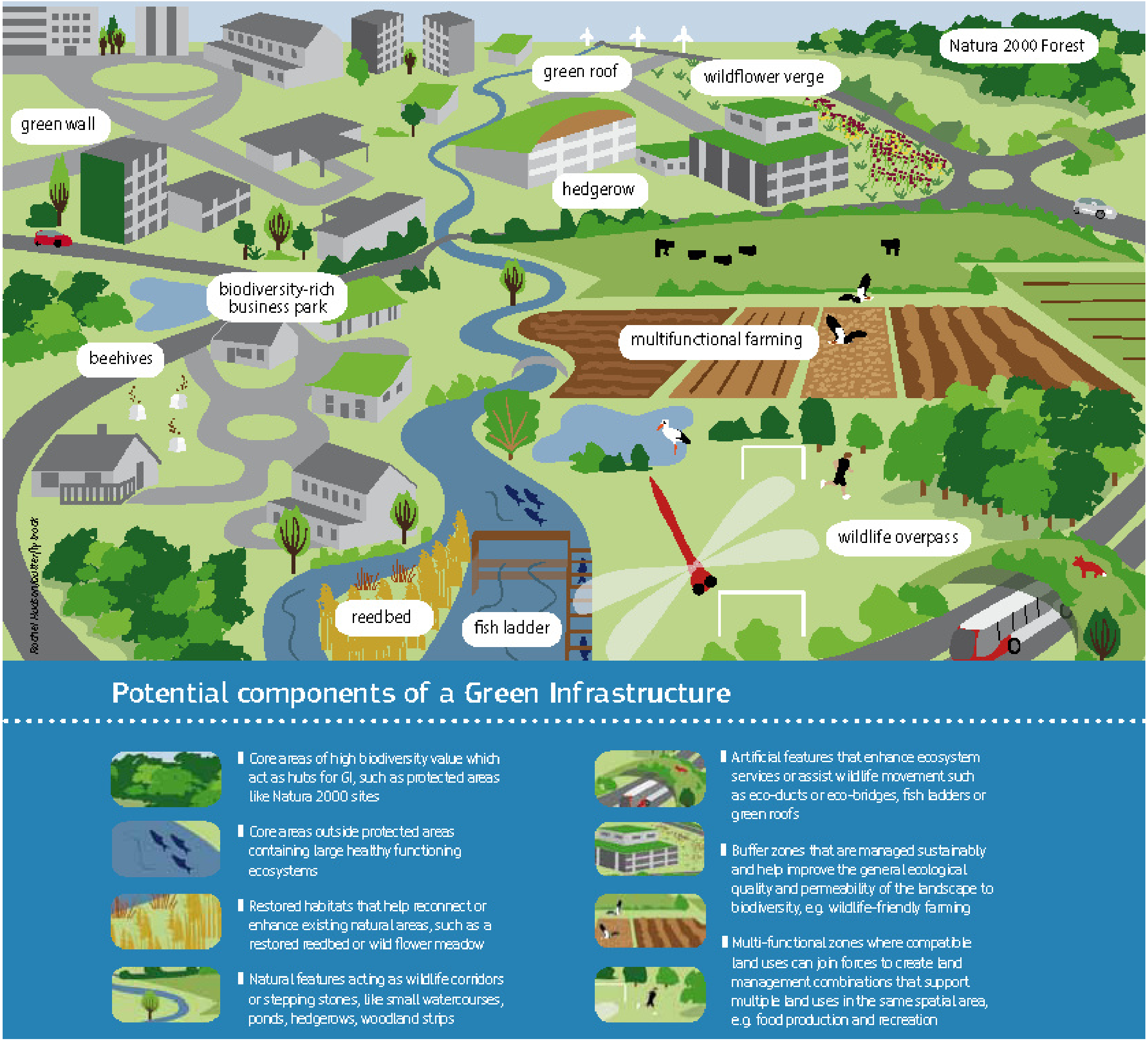


Figure 25: Potential components of green infrastructure
Source: https://ec.europa.eu/environment/nature/ecosystems/benefits/index_en.htm

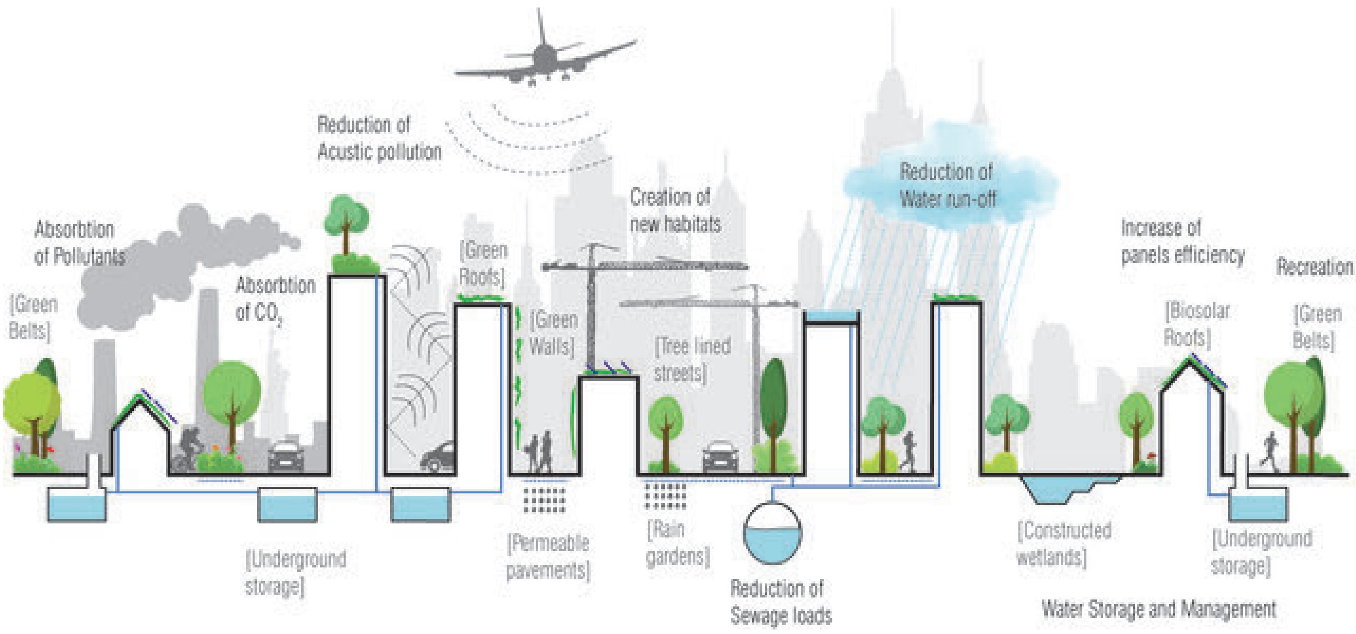


Figure 11: Ecosystem Services of Urban Green Infrastructure
Source: Catalano et al., 2017

2.4 Scopes of Green Infrastructure

Green infrastructure plays a significant role in enhancing the economy, improving community well-being, and benefiting the environment. Its scope encompasses various dimensions, and its impact is multifaceted. In this discussion, we will delve into the economic, community, and environmental aspects of green infrastructure, drawing from literatures

2.4.1 Economic Scope

2.4.1.1 Cost-Benefit Analysis

One of the key economic aspects of green infrastructure is its cost-effectiveness. Several studies, such as Perini and Rosasco (2013) and Hsu and Chao (2020), have discussed the importance of cost-benefit analysis to evaluate the economic viability of green infrastructure projects. These analyses consider factors like initial investment, maintenance costs, and long-term savings in terms of reduced energy consumption, improved property values, and lower healthcare expenses.

2.4.1.2 Property Values

Green infrastructure, such as parks, urban forests, and green roofs, can have a positive impact on property values. Research by Abdulateef and Al-Alwan (2022) found that urban green infrastructure can enhance the aesthetic appeal of neighborhoods, potentially increasing property values, which is an essential economic consideration.

2.4.1.3 Employment and Green Jobs

Green infrastructure projects, such as tree planting, landscaping, and park development, create employment opportunities. These projects require a skilled workforce, contributing to the local economy. The work by Jaffe (2010) and Kumar et al. (2019) addresses the employment and economic development aspects of green infrastructure.

2.4.2 Community Scope

2.4.2.1 Social Equity

Green infrastructure can play a vital role in addressing social equity concerns. It can provide communities with access to green spaces and amenities that promote physical and mental well-being, as discussed in the work by Gill et al. (2007) and Aram et al. (2019).

2.4.2.2 Health and Well-being

Urban green spaces contribute to community well-being. The study by Kumar et al. (2019) emphasizes the nexus between air quality, green infrastructure, and human health, highlighting the role of green spaces in mitigating pollution and providing health benefits.

2.4.2.3 Community Engagement

Involving communities in the planning and implementation of green infrastructure projects is essential. The work of Voghera and Giudice (2019) discusses the role of green infrastructure in community resilience and emphasizes the importance of community engagement.

2.4.3 Environmental Scope

2.4.3.1 Biodiversity

Green infrastructure can support biodiversity by creating habitats for various species. Zölch et al. (2016) and Aram et al. (2019) have examined the role of green infrastructure in enhancing biodiversity and promoting urban wildlife.

2.4.3.2 Air Quality and Climate

Green infrastructure contributes to improving air quality and mitigating urban heat island effects. The studies by Phelan et al. (2015) and Taleghani et al. (2019) discuss the mechanisms through which green infrastructure helps to cool cities, reduce air pollution, and mitigate climate change impacts.

2.4.3.3 Stormwater Management

The ability of green infrastructure to manage stormwater is a significant environmental benefit. It reduces the risk of flooding and helps maintain water quality, as highlighted in several works, including Balany et al. (2020) and Akbari et al. (2016).

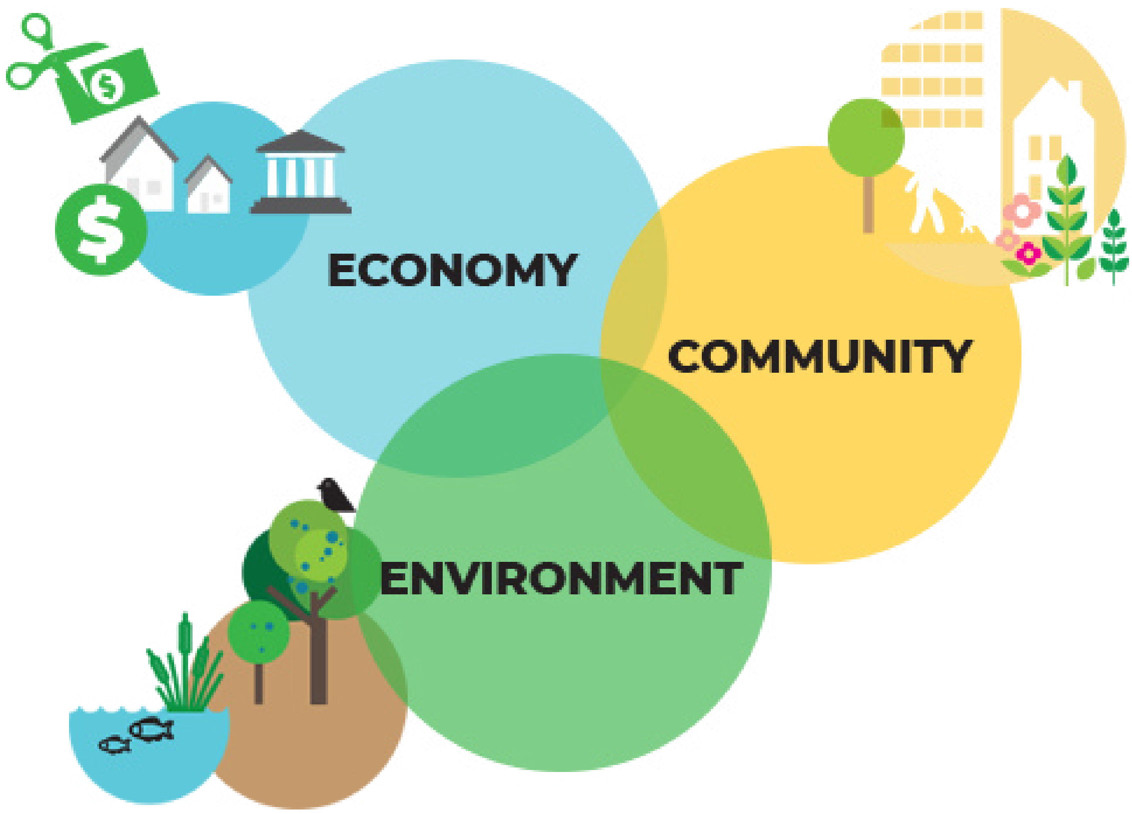


Figure 26: Scope of Green Infrastructure
Source: https://raincheckbuffalo.org/benefits-of-green-infrastructure/

CHAPTER 3

VALUATION OF GREEN INFRASTRUCTURE P

PROJECTS

3. Introduction

Green infrastructure (GI) plays a crucial role in urban planning and environmental management, especially in the context of climate change adaptation and sustainable development. The cost-benefit analysis (CBA) of green infrastructure has emerged as a vital tool for evaluating the economic implications and value of GI investments. This introduction provides an overview of the literature on the cost-benefit analysis of green infrastructure, drawing on relevant articles to highlight the importance and significance of conducting economic assessments of GI projects. The concept of green infrastructure encompasses a network of natural and semi-natural elements, such as parks, green spaces, urban forests, and green roofs, which provide numerous environmental, social, and economic benefits to urban areas. Gill et al. (2007) emphasize the role of green infrastructure in adapting cities for climate change and stress the importance of understanding its potential economic contributions. Jaffe (2010) focuses on the economics of green infrastructure, highlighting the need for comprehensive cost-benefit analyses to inform decision-making processes and policy development.

To conduct an effective cost-benefit analysis, various methodological approaches and frameworks have been employed. Naumann et al. (2011) explore the design, implementation, and cost elements of green infrastructure projects, offering practical insights into the evaluation process. Beauchamp and Adamowski (2012) discuss different methods for assessing the costs and benefits of green infrastructure in housing development projects, emphasizing the importance of integrating economic considerations with environmental and social aspects. Evaluating the economic value of specific components of green infrastructure, Perini and Rosasco (2013) focus on the cost-benefit analysis of green façades and living wall systems, shedding light on the economic feasibility of these specific interventions. Liu et al. (2016) present a case study on the cost-benefit analysis of green infrastructures for stormwater reduction and utilization in Beijing, China, highlighting the economic advantages of such interventions for community resilience and water management. Moreover, Mell et al. (2016) investigate the economic value of green infrastructure investments in The Wicker, Sheffield, emphasizing the potential for economic revitalization and increased property values. Hsu and Chao (2020) assess the economic valuation of green infrastructure investments in the station district of Taichung, Taiwan, demonstrating the potential benefits of incorporating GI in urban renewal projects.

In addition to methodological approaches, the literature also explores the tools and frameworks available for valuing green infrastructure. Van Oijstaeijen et al. (2020) provide a review of valuation toolkits from an urban planning perspective, offering insights into the practical application of economic valuation methods for green infrastructure projects. Ersoy Mirici (2022) conducts a systematic review on the economic valuation of ecosystem services provided by green infrastructure, highlighting gaps and research needs in this area. Considering the economic implications of green infrastructure maintenance, Qiao and Randrup (2022) investigate the willingness to pay for the maintenance of green infrastructure in Chinese pilot sponge cities, contributing to the understanding of the economic sustainability of GI projects. Nazir et al. (2015) explore the role of green infrastructure in determining house values using a hedonic pricing model, showcasing the potential economic benefits and market incentives associated with GI implementation.

3.1Theoretical framework

The theoretical framework for the cost-benefit analysis of green infrastructure is derived from the literature reviewed, providing a comprehensive understanding of the factors and considerations involved in assessing the economic implications of green infrastructure projects.

3.1.1 Economic Value of Green Infrastructure: The concept of economic value underpins the cost-benefit analysis of green infrastructure. Gill et al. (2007) highlight the role of green infrastructure in adapting cities for climate change, emphasizing the economic benefits derived from its implementation. Jaffe (2010) reflects on the economics of green infrastructure, acknowledging the need to assess and quantify its value. These studies emphasize the importance of economic valuation as a means to understand and communicate the benefits of green infrastructure.

3.1.2 Methodologies for Assessing Costs and Benefits: Several methodologies are employed to assess the costs and benefits of green infrastructure. Beauchamp and Adamowski (2012) discuss different methods used to assess the costs and benefits in housing development projects, providing insights into the diverse approaches available. Perini and Rosasco (2013) focus specifically on cost-benefit analysis for green façades and living wall systems, presenting a methodology for evaluating their economic value. These studies contribute to the theoretical framework by offering practical approaches for conducting cost-benefit analyses of green infrastructure projects.

3.13 Comprehensive Planning and Implementation: Effective design, implementation, and cost considerations play a vital role in the economic evaluation of green infrastructure. Naumann et al. (2011) emphasize the importance of comprehensive planning and cost elements in green infrastructure projects, highlighting the need for a holistic approach. Mell et al. (2016) examine the economic value of green infrastructure investments in Sheffield, emphasizing the importance of strategic planning and implementation. These studies underscore the significance of considering long-term costs and benefits in the theoretical framework.

3.14 Valuation Toolkits and Decision Support: Valuation toolkits and decision support frameworks are essential for assessing the economic value of green infrastructure. Van Oijstaeijen et al. (2020) review valuation toolkits from an urban planning perspective, providing insights into the methodologies and tools available for economic valuation. Hsu and Chao (2020) discuss the economic valuation of green infrastructure investments in urban renewal, highlighting the importance of decision support frameworks in guiding policymakers. These studies contribute to the theoretical framework by emphasizing the need for practical tools and frameworks to aid decision-making.

3.2 Methods Used in Cost-Benefit Analysis of Green Infrastructure

The literature provides insights into various methods used in the cost-benefit analysis of green infrastructure. These methods can be broadly categorized into economic valuation techniques, including **contingent valuation, hedonic pricing, cost-effectiveness analysis, cost-benefit analysis and the Integration of Multiple Methods.**

3.2.1 Contingent Valuation method

Contingent valuation is a method used to estimate the economic value of non-market goods and services. It involves surveys or interviews to elicit individuals' willingness to pay (WTP) for a particular environmental attribute or service provided by green infrastructure. Qiao and Randrup (2022) employ contingent valuation to determine the willingness to pay for the maintenance of green infrastructure in Chinese pilot sponge cities.

i. Conceptual Framework:

- The CVM is based on the idea that individuals can assign a value to non-market goods or services, such as improved air quality, biodiversity conservation, or recreational opportunities provided by green infrastructure.
- The method aims to capture the non-use or passive use value that individuals derive from these environmental attributes, which are not typically traded in markets.

ii. Survey Design:

- CVM surveys involve carefully designing questionnaires to elicit respondents' preferences and willingness to pay for specific aspects of green infrastructure.
- The surveys often employ hypothetical scenarios, describing the environmental improvements or changes that would result from the implementation of green infrastructure projects.
- The questionnaires typically include demographic information, the stated willingness to pay or willingness to accept compensation for the described changes, and additional questions to explore factors influencing respondents' preferences.

iii. Data Collection:

- Data for the CVM are collected through various methods, including face-to-face interviews, mail surveys, or online questionnaires.
- Sample sizes and respondent selection are crucial to ensure representativeness and reliability of the results.
- Researchers may use stratified sampling techniques to ensure a diverse and representative sample of the population being studied.

iv. Analysis and Valuation:

- The collected data are analyzed using statistical techniques, such as regression analysis, to estimate the relationship between respondents' stated preferences and their socio-economic characteristics.
- The estimated relationships are used to derive the economic values associated with different environmental attributes or changes in green infrastructure.
- The results often include aggregate measures, such as total economic value or average willingness to pay, and can be used to inform decision-making processes by comparing the costs and benefits of green infrastructure projects.

v. Limitations and Challenges:
- The CVM has some limitations and challenges, including potential biases and difficulties in accurately capturing individuals' true preferences and willingness to pay.
- Contingent valuation studies heavily rely on stated preferences rather than revealed preferences, which may introduce hypothetical bias or overstatement of values.
- Researchers must carefully address survey design issues, such as embedding, starting point bias, and protest responses, to mitigate potential biases and enhance the reliability of the results.

3.2.2 Hedonic Pricing method

Hedonic pricing is a method that analyzes the relationship between property prices and the presence or characteristics of certain amenities, such as green infrastructure. Nazir et al. (2015) utilize the hedonic pricing model to assess the role of green infrastructure in determining house values in Labuan. By analyzing property transactions and incorporating spatial data, the authors estimate the economic benefits associated with green infrastructure.

i. Conceptual Framework:
- The HPM is based on the assumption that the price or rent of a property is influenced by various attributes, including those associated with green infrastructure, such as proximity to parks, green spaces, or tree cover.
- The method recognizes that individuals are willing to pay more for properties that offer desirable environmental amenities or benefits, as reflected in the market prices or rents.

ii. Data Collection and Analysis:
- HPM studies collect data on property prices or rents, along with information on the attributes of the properties and the surrounding green infrastructure.
- Researchers use statistical techniques, such as regression analysis, to estimate the relationship between property values/rents and the green infrastructure attributes while controlling for other factors like location, property size, or building characteristics.
- The estimated coefficients for the green infrastructure attributes indicate the willingness of property buyers or renters to pay a premium for those attributes.

iii. Green Infrastructure Attributes:
- The HPM considers a range of green infrastructure attributes, such as proximity to parks, tree cover, access to recreational amenities, or the presence of green infrastructure features on the property itself (e.g., green roofs or rain gardens).
- These attributes capture the aesthetic, environmental, health, and social benefits associated with green infrastructure, which can enhance property values or rents.

iv. Economic Valuation:
- By analyzing the estimated coefficients from the regression models, researchers can quantify the economic value associated with each green infrastructure attribute.
- The values can be expressed as marginal price or rent premiums, indicating the additional price or rent premiums, indicating the additional amount that individuals are willing to pay for properties with specific green infrastructure features.
- These values provide insights into the economic benefits derived from green infrastructure investments and inform decision-making processes related to urban planning and development.

v. Limitations and Challenges:
- HPM studies face challenges such as the availability and quality of data, potential endogeneity issues, and the need to account for heterogeneity in preferences among property buyers or renters.
- The method relies on the assumption that property prices or rents accurately reflect individuals' preferences and willingness to pay for green infrastructure attributes.
- Researchers must carefully select control variables and address potential biases to ensure accurate estimation of the green infrastructure attribute values.

3.2.3 Cost-Effectiveness Analysis method

Cost-effectiveness analysis compares the costs and effectiveness of different alternatives or interventions. It aims to identify the most efficient way to achieve a specific objective. Liu et al. (2016) conduct a cost-benefit analysis of green infrastructures on community stormwater reduction and utilization in Beijing, China. The study evaluates the cost-effectiveness of different green infrastructure measures in reducing stormwater runoff and their subsequent benefits.

i. Conceptual Framework:
- CEA focuses on identifying and quantifying the costs and benefits of green infrastructure projects.
- The method aims to determine the most cost-effective projects by comparing the costs per unit of benefit across different alternatives.
- By assessing the efficiency of investment, CEA helps prioritize projects that deliver the greatest benefits relative to their costs.

ii. Data Collection and Analysis:
- CEA studies gather data on the costs associated with planning, designing, implementing, and maintaining green infrastructure projects.
- The benefits of green infrastructure can include improved air and water quality, reduced urban heat island effect, enhanced biodiversity, stormwater management, and recreational opportunities.
- Researchers estimate and monetize the benefits using various methods such as market prices, willingness to pay surveys, and expert judgments.
- The cost and benefit data are then used to calculate the cost-effectiveness ratio (cost per unit of benefit) for each project.

iii. Comparison and Decision-making:
- CEA involves comparing the cost-effectiveness ratios of different green infrastructure projects to identify the projects that provide the greatest benefits relative to their costs.
- Decision-makers can use the information to allocate resources efficiently and prioritize projects based on their cost-effectiveness.
tios indicate higher efficiency, as they deliver greater benefits per unit of cost.

iv. Sensitivity Analysis and Uncertainty:
- CEA studies often conduct sensitivity analyses to assess the robustness of results to changes in key assumptions or parameters.
- Uncertainty in the estimates of costs and benefits is addressed by incorporating ranges or probability distributions in the analysis.

- Sensitivity analysis helps decision-makers understand the potential variations in cost-effectiveness ratios under different scenarios or input assumptions.

v. Limitations and Challenges:

- CEA requires accurate and comprehensive data on costs and benefits, which can be challenging to obtain, particularly for non-market or intangible benefits.
- Valuing certain benefits, such as aesthetic or health improvements, can involve subjective judgments and uncertainty.
- The method may not capture all the social, cultural, and environmental dimensions of green infrastructure, potentially overlooking some important benefits that are difficult to monetize.

3.2.4 Cost-Benefit Analysis method

Cost-benefit analysis (CBA) is a widely used method that compares the costs an d benefits of a project or policy to determine its economic viability. It involves quantifying and monetizing the costs and benefits associated with green infrastructure projects. Beauchamp and Adamowski (2012) discuss different methods to assess the costs and benefits of green infrastructure in housing development projects, emphasizing the importance of considering both economic and non-economic factors.

i. Evaluation Framework:

- CBA involves the systematic comparison of the costs and benefits associated with different green infrastructure projects or interventions.
- It considers both monetary and non-monetary factors to assess the economic efficiency and overall desirability of investments.

ii. Cost Estimation:

- CBA studies estimate the costs of implementing and maintaining green infrastructure projects.
- Costs may include construction, operation, maintenance, and management expenses, as well as any necessary infrastructure upgrades or modifications.

iii. Benefit Assessment:

- CBA identifies and quantifies the benefits resulting from green infrastructure investments.
- Benefits can be categorized into direct and indirect, tangible and intangible, and include factors such as improved air quality, reduced flood risk, enhanced biodiversity, increased property values, and improved human well-being.
- Economic valuation techniques are often employed to assign monetary values to these benefits, allowing for a comprehensive comparison with costs.

iv. Discounting and Time Horizon:

- CBA considers the time value of money by discounting future costs and benefits to present values.
- A suitable time horizon is chosen to capture the costs and benefits over the expected lifespan of the green infrastructure project.

v. Cost-Benefit Ratio and Net Present Value:

- The cost-benefit ratio is calculated by dividing the total present value of benefits by the total present value of costs. A higher ratio indicates a more favorable investment.

- Net Present Value (NPV) assesses the overall economic viability of the investment by subtracting the total present value of costs from the total present value of benefits. A positive NPV signifies a financially desirable project

3.2.5 Integration of Multiple Methods

Van Oijstaeijen et al. (2020) highlight the importance of integrating multiple methods in green infrastructure valuation toolkits. This approach allows for a comprehensive assessment of various economic, social, and environmental aspects, considering both market and non-market values.

i. Quantitative and Qualitative Approaches:

- Green infrastructure valuation can combine quantitative methods, such as cost-benefit analysis and economic valuation techniques, with qualitative approaches to capture a broader range of impacts and values.
- Gill, S.E. et al. (2007) highlight the importance of integrating quantitative economic analysis with qualitative assessments to understand the multifunctionality and diverse benefits of green infrastructure in adapting cities to climate change.

ii. Economic Valuation Techniques:

- Economic valuation methods, such as hedonic pricing models and willingness-to-pay surveys, can be integrated into the valuation process to assign monetary values to non-market benefits of green infrastructure.
- Nazir, N.N.M. et al. (2015) employ a hedonic pricing model to assess the role of green infrastructure in determining house values, incorporating both quantitative and qualitative factors into the valuation analysis.

iii. Cost-Benefit Analysis and Cost-Effectiveness Analysis:

- Combining cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) allows for a comprehensive evaluation of green infrastructure projects.
- Beauchamp, P., and Adamowski, J. (2012) discuss different methods, including CBA and CEA, to assess the costs and benefits of green infrastructure in housing development projects, providing a comparative analysis of the two approaches.

iv. Ecosystem Services Assessment:

- The integration of ecosystem services assessment frameworks allows for a holistic evaluation of the ecological and socio-economic benefits provided by green infrastructure.
- Ersoy Mirici, M. (2022) emphasizes the importance of integrating ecosystem services valuation into the economic assessment of green infrastructure, highlighting the need to bridge the gap in economic valuation research.

v. Multi-Criteria Decision Analysis:

- Multi-criteria decision analysis (MCDA) techniques can be employed to incorporate various factors and stakeholders' perspectives in the valuation process.
- Hsu, K.W., and Chao, J.C. (2020) utilize MCDA to assess the economic value of green infrastructure investments in urban renewal projects, considering multiple criteria, such as environmental, social, and economic aspects.

3.3 Most effective valuation method of green infrastructure based on the research

The hedonic pricing method is widely recognized as one of the most effective approaches for valuing green infrastructure (GI) in real estate practice. This method determines the economic value of GI by examining the relationship between property prices and the presence or quality of green features. This discussion will delve into the reasons why the hedonic pricing method is considered the best approach for valuing GI in real estate practice.

3.3.1 Market-Based Valuation: The hedonic pricing method is a market-based valuation approach that relies on actual transactions and property market data. It captures the preferences of buyers and sellers in the real estate market and reflects the economic value that individuals attribute to the presence of green infrastructure (Li et al., 2019; Zhou et al., 2020). By analyzing property sales data and incorporating the characteristics of GI, such as proximity to parks, tree canopy cover, or access to green spaces, the hedonic pricing method provides a robust and objective estimation of the economic value of GI.

3.3.2 Consideration of Multiple Factors: The hedonic pricing method accounts for various property characteristics, including the presence of GI, in determining property prices. It considers not only the physical attributes of GI but also other factors such as location, size, amenities, and neighborhood characteristics (González et al., 2019; He et al., 2018). This method enables the separation of the specific value associated with GI from other factors that influence property prices, allowing for a more accurate valuation of the green features.

3.3.3 Accessibility and Amenity Value: One of the key advantages of the hedonic pricing method is its ability to capture the accessibility and amenity value of GI. Research has shown that proximity to green spaces, parks, and natural areas positively influences property values (Wu and Plantinga, 2003; Zhang et al., 2019). The hedonic pricing method allows for the quantification of the premium or price increment associated with the presence of GI amenities, providing valuable information for property valuation and investment decisions.

3.3. 4 Non-Market Valuation Limitations: While non-market valuation methods, such as contingent valuation or stated preference surveys, can provide insights into individuals' willingness to pay for GI, they often suffer from hypothetical bias and may not accurately reflect actual market behavior (Lindhjem and Navrud, 2011; Navrud and Ready, 2007). In contrast, the hedonic pricing method overcomes these limitations by relying on observed market data and real transactions, making it a more reliable and credible approach in real estate practice.

3.3.5. Policy Support and Acceptance: The hedonic pricing method has gained wide acceptance and support from policymakers, urban planners, and real estate professionals. Its use is well-established and recognized by regulatory bodies and market stakeholders (Fuerst and McAllister, 2011; Massetti and Seyedghase mipour, 2020). The transparency and objectivity of the hedonic pricing method make it easier to integrate into existing real estate appraisal and valuation practices, facilitating informed decision-making and policy development related to GI investments.

In conclusion, by utilizing this method, stakeholders in the real estate sector can better understand and quantify the economic value of green infrastructure, leading to informed investment decisions, sustainable urban planning, and the promotion of green and resilient cities.

CHAPTER 4

INNOVATIVE TOOLS, TECHNOLOGIES, AND STRAT
IN THE DESIGN AND IMPLEMENTATION OF GREEN

TEGIES EMPLOYED
N INFRASTRUCTURE PROJECTS

4. Innovative tools, technologies, and strategies

Green infrastructure (GI) plays a crucial role in mitigating the urban heat island (UHI) effect and improving the sustainability of cities. To enhance the design and implementation of GI projects, various innovative tools, techniques, technologies, and strategies have been developed. This section explores some of these advancements, drawing upon the information provided in the reviewed literatures.

4.1.1 Geographic Information Systems (GIS)

GIS technology plays a crucial role in green infrastructure planning and implementation. It allows for the integration and analysis of spatial data, facilitating informed decision-making and effective resource allocation (Bowler et al., 2010). GIS tools enable the identification and mapping of suitable locations for green infrastructure elements, such as green spaces, tree planting, and permeable surfaces, based on factors like land use, land cover, and topography (Cariñanos et al., 2017). This information helps optimize the placement and distribution of green infrastructure, maximizing its benefits in mitigating urban heat island effects and improving environmental quality.

4.1.2 Sensor Technologies and Data Analytics

Advancements in sensor technologies and data analytics have revolutionized the monitoring and management of green infrastructure projects. Wireless sensor networks, IoT devices, and remote sensing platforms enable real-time monitoring of environmental parameters such as temperature, humidity, soil moisture, and air quality. Data analytics tools provide valuable insights for optimizing the design, maintenance, and performance of green infrastructure systems, enabling proactive decision-making and efficient resource allocation (Wang et al., 2020; Li et al., 2021).

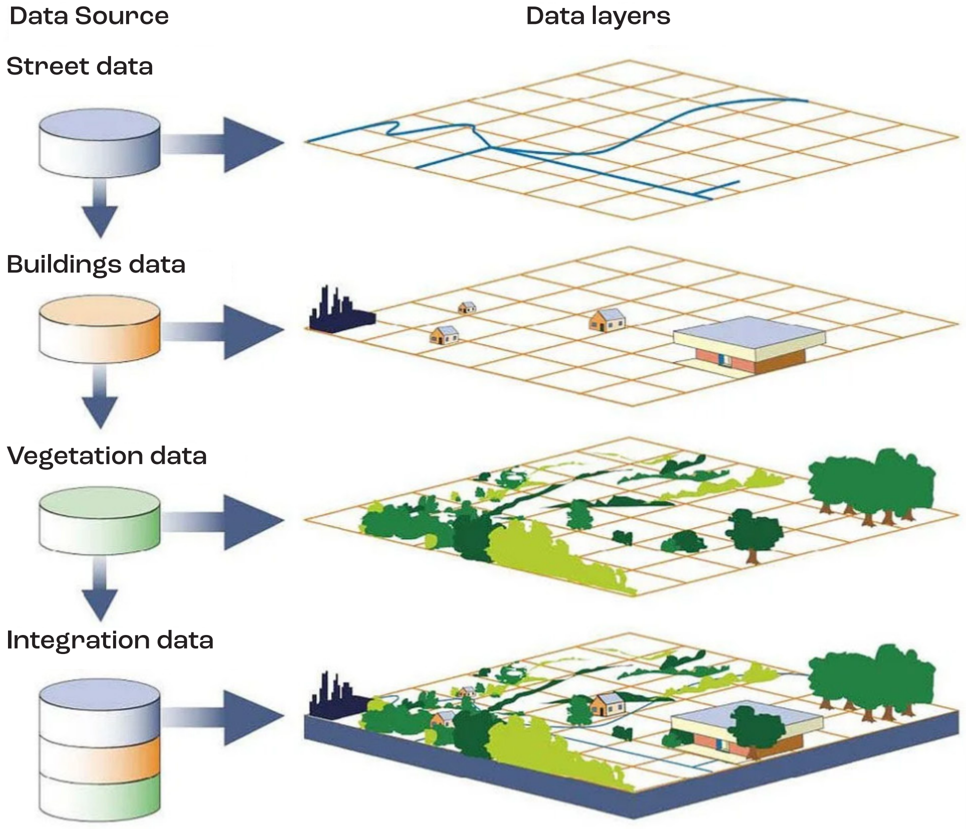


Figure 27:GIS application
Source: illustration courtesy of U.S. government accountability office

4.1.3 Urban Tree Planting and Design

Trees provide multiple benefits in urban areas, including shading, temperature reduction, and air quality improvement. Innovations in urban tree planting and design aim to maximize these benefits. For example, using native tree species that are well-adapted to local climate conditions can enhance tree survival and growth. Tree planting strategies, such as the implementation of tree trenches, silva cells, and suspended pavement systems, ensure adequate soil volume for tree root growth and facilitate stormwater management (Nowak and Greenfield, 2018; Sanusi et al., 2019).

4.1.4 Green Infrastructure Suitability Analysis Tool

Green infrastructure suitability analysis tools assist in identifying suitable locations for the implementation of green infrastructure projects. These tools consider multiple factors, such as land use, land cover, soil types, topography, and proximity to water bodies, to assess the suitability and potential effectiveness of green infrastructure interventions. Using spatial analysis techniques and GIS, these tools help prioritize areas where green infrastructure can provide maximum benefits, such as stormwater management, urban cooling, and biodiversity enhancement (Rivard et al., 2016; Yu et al., 2017).

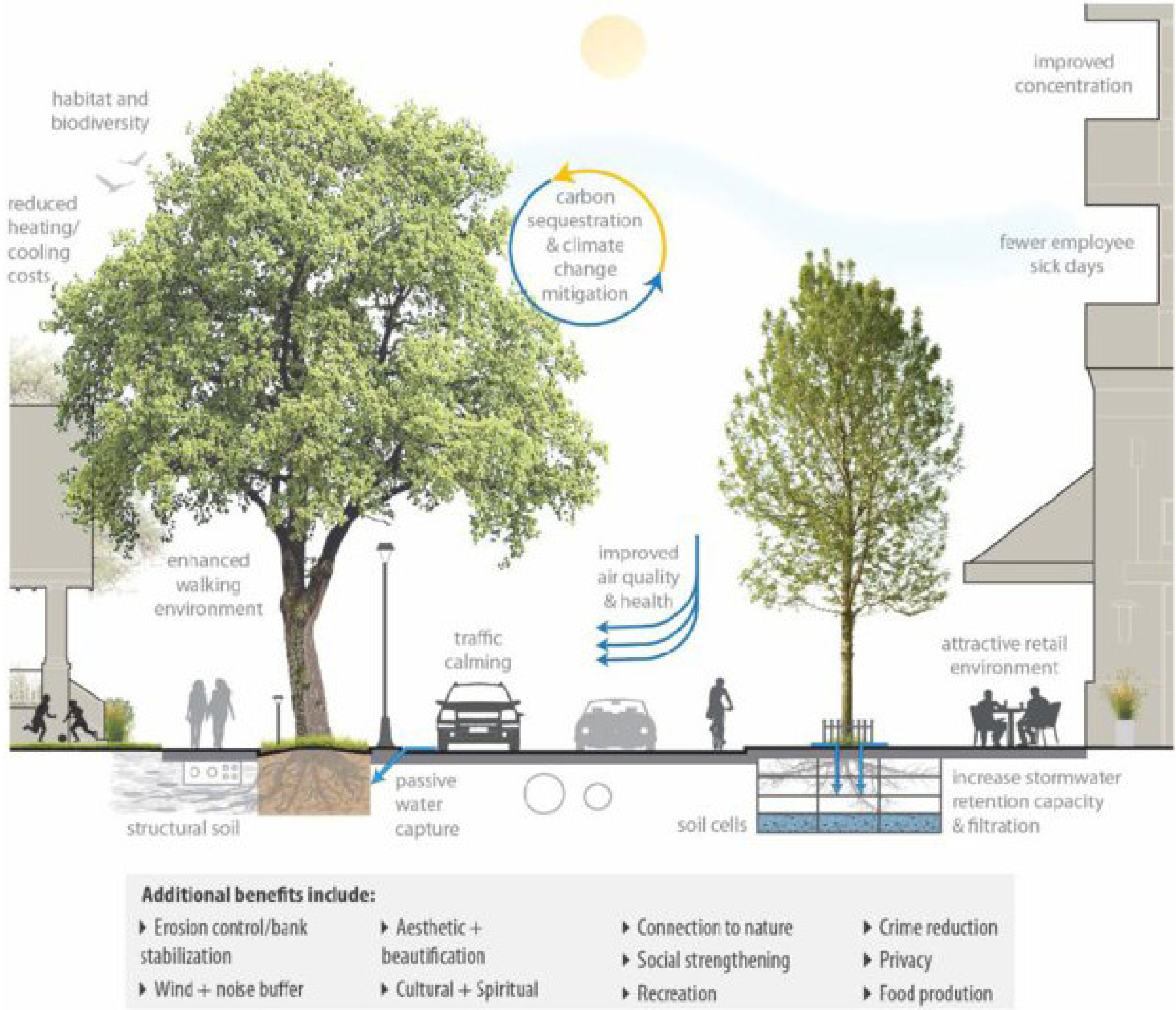


Figure 28: Street tree benefits.
Source: Amelia Needoba, Trevor Cox, and Camille B. Lefrançois, Oak Bay Urban Forest Management Strategy (2017).

4.1.5 Participatory Mapping and Visualization

Engaging stakeholders and communities in the design and implementation of green infrastructure projects is essential for their success. Participatory mapping and visualization techniques involve involving local residents, policymakers, and experts in the decision-making process (Talen, 2013). These techniques use interactive mapping tools and visual representations to gather input, preferences, and local knowledge, which can inform the design and implementation of green infrastructure projects (Van Herzele & Wiedemann, 2003). Participatory approaches enhance community involvement, promote social equity, and increase the sense of ownership and stewardship of green infrastructure (Huang et al., 2016).

4.1.6 Nature-Based Solutions

Nature-based solutions involve utilizing natural ecosystems and processes to address environmental challenges. This approach emphasizes the integration of green infrastructure with existing natural systems, such as wetlands, forests, and water bodies, to enhance their capacity for environmental and social benefits (Bulkeley & Broto, 2013). Nature-based solutions contribute to climate change adaptation, biodiversity conservation, and ecosystem restoration while providing multiple co-benefits, including improved air and water quality, carbon sequestration, and recreational opportunities (Bulkeley et al., 2019).

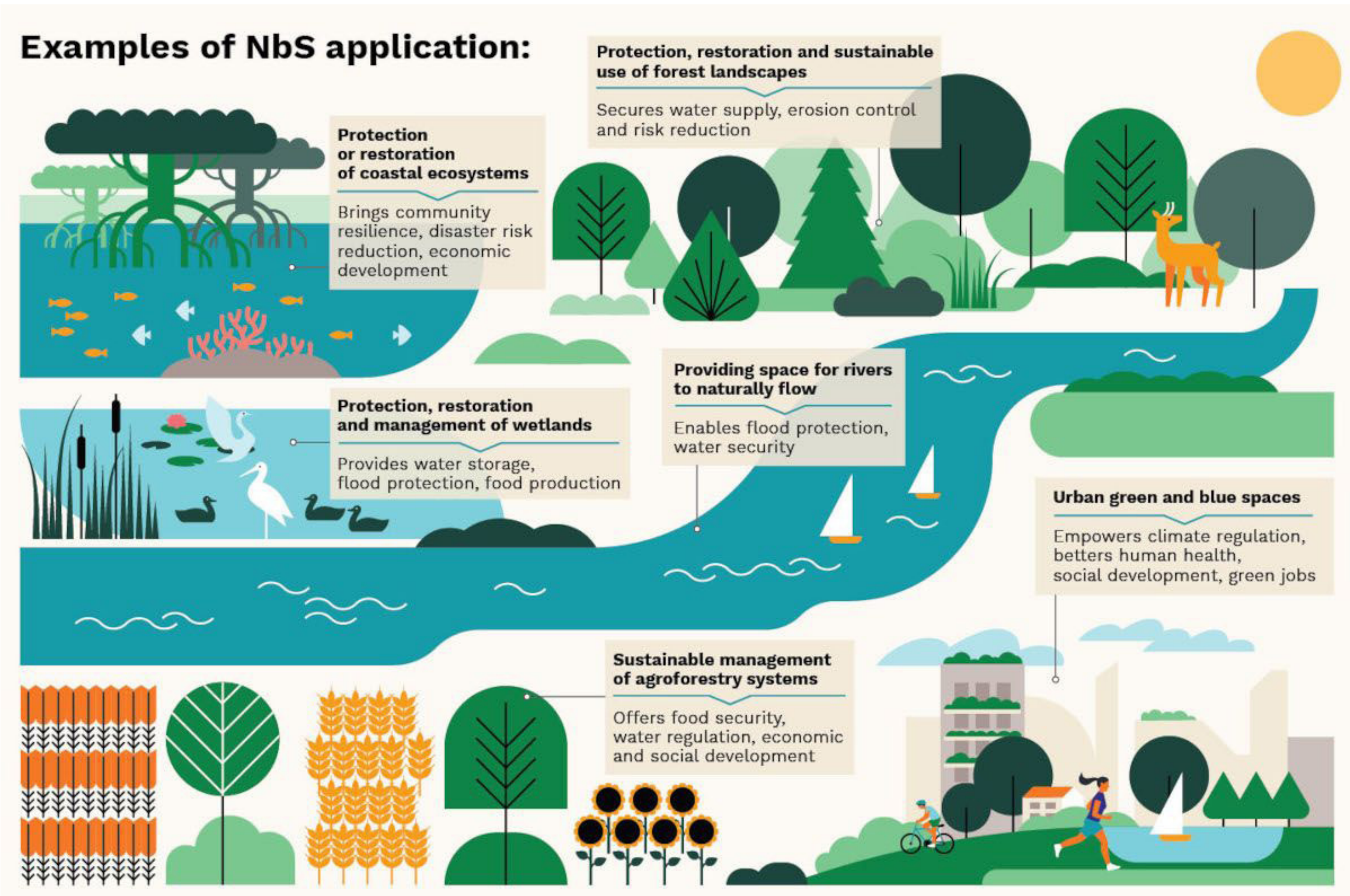


Figure 29: NBS, applications and benefits
Source: https://www.infobuild.it/approfondimenti/consumo-di-suolo-cementificazione-run-off-alluvioni-frane/

4.1.7 Permeable Pavement Systems

Traditional impermeable pavements exacerbate the UHI effect by reducing infiltration and increasing surface runoff. Permeable pavement systems, on the other hand, allow water to infiltrate into the ground, reducing runoff and improving stormwater management. These systems utilize various materials, such as permeable concrete, porous asphalt, and interlocking pavers, which enable water to percolate through the pavement surface. Advances in pavement design, including enhanced permeability and structural integrity, have led to the development of more durable and effective permeable pavement systems (Huang et al., 2010; Lucke et al., 2013).

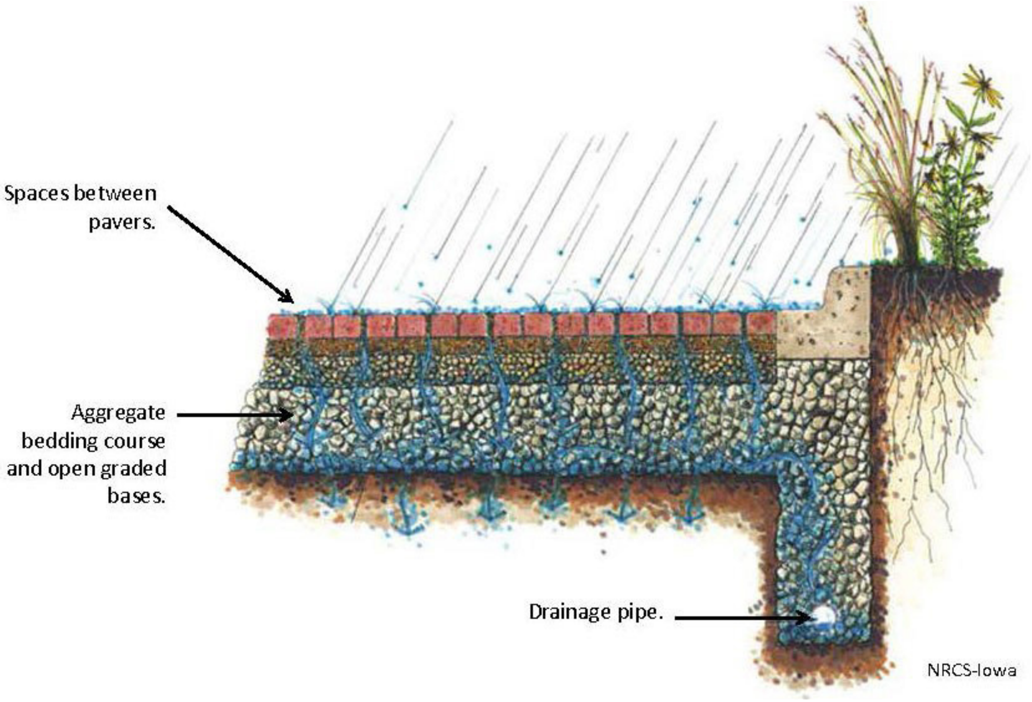


Figure 30: Typical permeable pavement sections
Source: https://metroblooms.org/permeable-pavement-maintenance/

4.1.8 Cool Pavement Technologies

Traditional dark-colored pavements absorb a significant amount of solar radiation, contributing to the UHI effect. Cool pavement technologies, such as reflective coatings and light-colored materials, help to reduce surface temperatures. These materials have high solar reflectance and thermal emittance, minimizing the absorption and retention of solar heat. Cool pavements can effectively lower ambient temperatures, especially in parking lots, streets, and other high-traffic areas (Akbari et al., 2001;
Santamouris, 2015).

Figure 31: Differences between Dark and Cool pavement
Source:heatisland.lbl.gov

4.2 Modeling and Simulation Tools

In the design and implementation of Green Infrastructure projects, various modeling and simulation tools are employed to analyze, evaluate, and optimize different aspects of green infrastructure interventions. This section discusses some of the different modeling and simulation tools commonly used in the context of Green Infrastructure, drawing upon the information provided previously.

4.2.1 Hydrological Models

Hydrological models, such as **SWMM (Storm Water Management Model) and HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System),** are widely used in Green Infrastructure projects to simulate the movement of water within a watershed. These models help assess the performance of green infrastructure elements in managing stormwater runoff, including features like permeable pavements, rain gardens, and retention ponds. By considering factors such as rainfall patterns, land use, and soil characteristics, hydrological models can evaluate the effectiveness of different green infrastructure interventions in reducing runoff volume and improving water quality (Cheng et al., 2019).

4.2.2 Energy Modeling Tools

Energy modeling tools are employed to assess the energy performance of green infrastructure elements and their impact on buildings and urban microclimates. These tools analyze the energy savings potential of green roofs, solar panels, and other energy-efficient interventions. **EnergyPlus and IES VE (Integrated Environmental Solutions Virtual Environment)** are examples of energy modeling tools commonly used in Green Infrastructure projects (Kośny et al., 2020). They simulate the energy consumption and thermal behavior of buildings in relation to green infrastructure features, aiding in the optimization of energy-efficient designs.

4.2.3 Green Roof Simulation Tools

Green roof simulation tools are specifically designed to evaluate the performance of green roofs in terms of stormwater management, energy savings, and biodiversity enhancement. These tools consider factors such as plant species, substrate depth, and roof characteristics to simulate the hydrological and thermal behavior of green roofs. Examples of green roof simulation tools include **GRASS (Green Roof Aero-Subsurface Simulation) and STORM (Stormwater Management Model)** (Stovin et al., 2017). These tools assist in optimizing green roof designs to achieve desired performance outcomes.

4.2.4 Multi-Criteria Decision Analysis (MCDA) Tools

MCDA tools facilitate decision-making in Green Infrastructure projects by considering multiple criteria and objectives. These tools assist in comparing and evaluating different design alternatives based on various criteria, such as cost-effectiveness, environmental benefits, and social equity. A commonly used MCDA tool is **Analytic Hierarchy Process (AHP)**, which enables the prioritization and selection of green infrastructure strategies based on weighted criteria (Famulari et al., 2020). MCDA tools aid in supporting transparent and systematic decision-making processes in Green Infrastructure projects.

4.2.5 Urban Climate Models

Urban climate models simulate the microclimate conditions within urban areas, including temperature, wind patterns, and air quality. These

models are utilized to assess the cooling effects of green infrastructure interventions, such as urban parks and green spaces. **The SOLWEIG model** and **ENVI-met (Environmental Meteorology)** are examples of urban climate models used in Green Infrastructure projects (Liu et al., 2019). By simulating the impact of green infrastructure on urban heat island effects and air quality, these models support the design of interventions that enhance thermal comfort and reduce air pollution.

4.3 Factors influencing the effectiveness of green infrastructure in urban heat island mitigation

Green infrastructure (GI) has gained recognition as an effective strategy for mitigating urban heat island (UHI) effects. However, the effectiveness of GI in UHI mitigation can vary due to several influential factors. This section explores key factors that influence the effectiveness of GI in UHI mitigation, highlighting the importance of design, scale, context, and maintenance.

4.3.1. Design Characteristics

The design characteristics of green infrastructure elements significantly influence their effectiveness in UHI mitigation. Factors such as vegetation type, density, distribution, and arrangement of green spaces, and the selection of suitable materials play a crucial role. Studies have shown that maximizing vegetation cover and diversity, incorporating larger tree canopy areas, and utilizing high-albedo materials can enhance the cooling effect and reduce UHI intensity (Akbari et al., 2001; Dobbs et al., 2011).

4.3.1.1 Vegetation Type: The choice of vegetation type in GI projects significantly affects their cooling potential. Studies have shown that deciduous trees and vegetation with high water use efficiency, such as grasses and shrubs, provide effective shading and evapotranspiration, resulting in substantial temperature reduction (Coutts et al., 2012; Dobbs et al., 2011). These vegetation types contribute to lowering ambient temperatures by intercepting solar radiation, absorbing heat, and releasing moisture through transpiration.

4.3.1.2 Vegetation Density and Coverage: The density and coverage of vegetation within GI projects influence their cooling effects. Higher vegetation density, such as an increased number of trees or more extensive green roofs, can create denser shade and increase evapotranspiration, leading to more significant temperature reductions (Akbari et al., 2001; Coutts et al., 2016). Studies have demonstrated that higher canopy cover and leaf area index contribute to more substantial UHI mitigation benefits (Coutts et al., 2012; Dobbs et al., 2011).

4.3.1.3 Green Roof Characteristics:
Green roofs are an essential component of GI in urban areas. The design characteristics of green roofs, including vegetation type, substrate depth, and irrigation systems, influence their cooling effects. Research has found that green roofs with a diverse mix of vegetation, such as grasses, herbs, and sedums, provide better UHI mitigation compared to monoculture roofs (Coutts et al., 2016). Additionally, deeper substrate layers and irrigation systems that maintain adequate soil moisture contribute to higher evapotranspiration rates and better cooling performance (Coutts et al., 2012).

4.3.1.4 Permeable Pavements: Permeable pavements are another design feature of GI projects that contribute to UHI mitigation. The type and permeability of pavement materials impact their cooling potential. Permeable pavements allow water infiltration into the soil, promoting evapotranspiration and reducing surface temperatures (Escobedo et al., 2011). Studies have shown that higher permeability pavements, such as porous asphalt or permeable concrete, offer better cooling effects than traditional impermeable pavements (Akbari et al., 2001).

4.3.1.5 Urban Green Spaces: The design characteristics of urban green spaces, including parks, plazas, and green corridors, also influence their UHI mitigation potential. Design elements such as tree spacing, orientation, and arrangement contribute to shading and air movement, which affects temperature reduction. Well-designed green spaces with a mix of vegetation, shaded seating areas, and water features can create microclimates that provide relief from UHI effects (Dobbs et al., 2011; Coutts et al., 2012).

4.3.2 Spatial Distribution

The spatial distribution of green infrastructure elements within urban areas is a critical factor in determining their effectiveness in UHI mitigation. Strategic placement of GI elements considering their proximity to built-up areas, high-temperature zones, and areas with high population density can maximize their impact. Concentrating GI in UHI hotspots and creating green corridors or networks can enhance their cooling effect and promote air circulation (Gaffin et al., 2012).

4.3.2.1 Connectivity and Configuration: The connectivity and configuration of green spaces within an urban area influence their cooling potential. Studies have shown that a well-connected network of green spaces, such as parks, green corridors, and tree-lined streets, can facilitate air movement, create shade, and promote the flow of cool air through the urban landscape (Li et al., 2017; Nowak et al., 2010). When GI elements are strategically distributed to form a connected and continuous network, they can enhance the cooling effects by reducing the heat island intensity across a larger area (Bowler et al., 2010).

4.3.2.2 Proximity to Heat Sources: The spatial distribution of GI relative to heat sources, such as buildings, roads, and industrial areas, can influence its effectiveness in UHI mitigation. Placing GI elements, such as trees and green roofs, in close proximity to heat-emitting sources can help intercept and absorb solar radiation, reducing the heat load on nearby surfaces (Liu et al., 2017; Peng et al., 2014). By strategically locating GI to provide shade and block direct sunlight, the UHI effects can be mitigated more effectively in areas with high heat emissions.

4.3.2.3 Spatial Equity and Access: The equitable distribution of GI across urban areas is crucial to ensure that all communities benefit from UHI mitigation. Research has highlighted the importance of considering social and spatial equity in the planning and distribution of GI (Pauleit et al., 2011). By prioritizing the implementation of GI projects in neighborhoods with limited green spaces and higher UHI intensities, the cooling benefits can be distributed more equitably, addressing environmental justice concerns.

4.3.2.4 Urban Form and Context: The spatial characteristics of the urban form and context, including building height, street layout, and land use patterns, interact with GI distribution to influence UHI mitigation. Research suggests that integrating GI elements within the urban fabric, considering factors like street orientation and building design, can optimize shading and cooling effects (Loughnan et al., 2012; Wong et al., 2019). The spatial arrangement of GI should be tailored to the specific urban context to maximize its effectiveness.

4.3.3 Scale of Implementation

The scale at which green infrastructure is implemented can influence its effectiveness in UHI mitigation. While localized GI interventions can provide localized cooling benefits, the overall UHI mitigation effectiveness can be enhanced by considering larger-scale implementation. Implementing GI at the neighborhood or citywide scale can create a cumulative cooling effect, especially when connected through green corridors and networks (Santamouris et al., 2017).

4.3.3.1 Neighborhood Scale: Implementing GI at the neighborhood scale involves targeting specific areas or communities within a city. Research has shown that implementing GI interventions at the neighborhood level can lead to localized cooling effects and reduce UHI intensity within those areas (Santamouris et al., 2017; Sun et al., 2020). Examples of neighborhood-scale GI interventions include the creation of green parks, the installation of green roofs, and the planting of trees in residential areas. By focusing on specific neighborhoods, UHI mitigation efforts can address local environmental challenges and improve residents' quality of life.

4.3.3.2 City Scale: Implementing GI projects at the city scale involves integrating green infrastructure across the entire urban area. Studies have demonstrated that large-scale implementation of GI, such as increasing tree canopy cover, implementing green spaces, and creating urban forests, can have substantial cooling effects and mitigate UHI on a broader scale (Escobedo et al., 2018; Zhang et al., 2019). City-scale GI projects can reduce the overall UHI intensity, enhance the urban microclimate, and improve the ecological resilience of the entire city.

4.3.3.3 Regional/ Metropolitan Scale: At the regional or metropolitan scale, GI interventions are implemented across a wider geographical area, encompassing multiple cities or urban regions. Research has shown that coordinated efforts to implement GI strategies at the regional scale can lead to significant UHI mitigation effects (Churkina et al., 2017; Gómez-Baggethun et al., 2013). Regional-scale GI projects may include large-scale afforestation programs, the establishment of green corridors connecting urban areas, and the creation of regional parks. By considering the broader regional context, UHI mitigation efforts can address cross-boundary impacts and promote collaborative decision-making among multiple stakeholders.

4.3.3.4 Multi-scale Approaches: Combining GI interventions at different scales, such as integrating neighborhood-scale projects within a city-wide strategy or connecting city-scale projects within a regional framework, can enhance the effectiveness of UHI mitigation efforts (Fan et al., 2021; Li et al., 2019). Multi-scale approaches acknowledge the complex spatial interactions and interdependencies within urban systems and provide opportunities for synergistic effects and comprehensive UHI mitigation outcomes.

4.3.3.5 Adaptive Management: Adaptive management approaches emphasize the dynamic nature of UHI mitigation and the need for flexibility in scaling GI interventions over time. Research suggests that adaptive management strategies, such as iterative planning processes, continuous monitoring, and feedback loops, can improve the effectiveness of UHI mitigation efforts (McDonald et al., 2019; Santamouris et al., 2020). By adjusting the scale of implementation based on evolving urban conditions and feedback from monitoring systems, GI interventions can adapt to changing environmental, social, and economic contexts.

4.3.4 Urban Context

The effectiveness of GI in UHI mitigation is also influenced by the specific urban context, including factors such as land use patterns, building density, and urban morphology. Urban areas with higher building densities and limited green spaces may experience stronger UHI effects. Therefore, the design and implementation of GI should be context-specific, considering the unique characteristics and challenges of each urban area (Akbari et al., 2001).

4.3.4.1 Urban Morphology and Layout: The physical layout and morphology of the city, including building density, street orientation, and urban form, can influence the effectiveness of GI in UHI mitigation. Research has shown that compact and dense urban forms with high-rise buildings can create urban canyons that restrict air movement and exacerbate UHI effects (Oke, 1987; Wong et al., 2019). In such contexts, strategically integrating GI elements, such as street trees, green roofs, and vertical greening systems, can help mitigate UHI effects by providing shade, reducing surface temperatures, and promoting evaporative cooling (Song et al., 2020; Wong et al., 2018).

4.3.4.2 Land Use Patterns and Composition: The land use patterns and composition of the city influence the availability of open spaces for GI implementation and the distribution of heat sources. Research has demonstrated that land use composition, such as the proportion of built-up areas, vegetation cover, and water bodies, can impact UHI intensity (Yang et al., 2018; Zhang et al., 2020). Mixed land use with a diverse range of vegetation types, including parks, green spaces, and natural areas, can provide more opportunities for GI implementation and contribute to UHI mitigation.

4.3.4.3 Socioeconomic Factors: Socioeconomic factors, including income levels, social demographics, and community engagement, can influence the effectiveness of GI in UHI mitigation. Studies have shown that the distribution of GI interventions may be uneven across different socioeconomic neighborhoods, leading to disparities in cooling benefits and exacerbating environmental injustices (Heynen et al., 2006; Wolch et al., 2014). Ensuring equitable access to GI and involving local communities in the planning and implementation processes can enhance the effectiveness and acceptance of UHI mitigation strategies (Santamouris et al., 2018; Xiao et al., 2019).

4.4.4.4 Institutional and Policy Framework: The institutional and policy framework of a city can either facilitate or hinder the implementation of GI for UHI mitigation. Supportive policies, regulations, and planning frameworks that promote green infrastructure, sustainable design, and urban greening can provide an enabling environment for effective UHI mitigation (Gómez-Baggethun et al., 2013; Pham et al., 2019). Collaboration among different government agencies, stakeholders, and community groups is essential for integrated planning and implementation of GI projects (Kabisch et al., 2016; Pickett et al., 2017).

(Gómez-Baggethun et al., 2013; Pham et al., 2019). Collaboration among different government agencies, stakeholders, and community groups is essential for integrated planning and implementation of GI projects (Kabisch et al., 2016; Pickett et al., 2017).

4.3.4.5 Climate and Microclimate Variability: The local climate and microclimate conditions, including temperature, humidity, wind patterns, and solar radiation, influence the effectiveness of GI in UHI mitigation. Research suggests that the climatic context of a city, such as its location, prevailing wind directions, and regional climate patterns, should be considered when designing and implementing GI interventions (Jiang et al., 2019; Ryu et al., 2020). Tailoring GI strategies to the specific climate and microclimate conditions can optimize their cooling effects and enhance UHI mitigation outcomes.

4.3.5 Maintenance and Management

The long-term effectiveness of GI in UHI mitigation depends on proper maintenance and management. Regular upkeep of green infrastructure elements, including pruning, irrigation, and pest control, is essential to ensure their health and vitality. Adequate funding, community engagement, and involvement of relevant stakeholders are crucial for the sustained maintenance and management of GI projects (United Nations Environment Programme, 2019).

4.3.5.1 Vegetation Health and Maintenance: The health and maintenance of vegetation, such as trees, plants, and green roofs, directly influence their cooling effects and UHI mitigation potential. Regular maintenance activities, including pruning, watering, fertilizing, and pest control, are necessary to ensure the vitality and longevity of vegetation (Emmanuel et al., 2007; Li et al., 2015). Adequate irrigation and watering practices are particularly important to sustain vegetation during hot and dry periods, maintaining their transpirational cooling effects (Li et al., 2020). Regular monitoring and prompt management of vegetation health issues, such as diseases and pests, are crucial to maintain the cooling benefits of GI.

4.3.5.2 Stormwater Management: GI elements, such as green roofs, rain gardens, and permeable pavements, contribute to stormwater management and can reduce UHI effects. Effective maintenance and management of stormwater infrastructure are essential to ensure proper water infiltration, reduce runoff, and maintain the functionality of GI (Stovin et al., 2012; Volder et al., 2014). Regular inspections, cleaning of drainage systems, and sediment removal are necessary to prevent clogging and ensure the efficient functioning of stormwater management components.

4.3.5.3 Irrigation and Water Conservation: Water availability and efficient irrigation practices are crucial for the success of GI interventions. Research suggests that optimizing irrigation techniques, such as using smart irrigation systems and drought-tolerant plant species, can reduce
water consumption while sustaining vegetation health (Kong et al., 2014; Wong et al., 2021). Monitoring soil moisture levels and adjusting irrigation schedules based on weather conditions can promote water conservation and enhance the effectiveness of GI in UHI mitigation.

4.3.5.4 Monitoring and Data Collection:

Regular monitoring and data collection are essential for assessing the performance and effectiveness of GI in UHI mitigation. Monitoring techniques, such as remote sensing, sensor networks, and data collection platforms, can provide valuable information on temperature patterns, vegetation health, and microclimate conditions (Nguyen et al., 2020; Voogt et al., 2017). Continuous monitoring allows for early detection of maintenance issues, facilitates informed decision-making, and enables adaptive management of GI interventions.

4.3.5.5 Community Engagement and Participation: Engaging the community in the maintenance and management of GI can enhance its effectiveness in UHI mitigation. Encouraging community participation in tree planting initiatives, community gardens, and maintenance activities fosters a sense of ownership, improves GI stewardship, and ensures the long-term success of UHI mitigation efforts (Dunn et al., 2018; Tidball et al., 2017). Community-led monitoring and reporting systems can also provide valuable feedback on maintenance needs and help address issues promptly.

CHAPTER 5
LESSONS LEARNED

5.1 Passeig de Sant Joan Boulevard

Location: Barcelona, Spain
Size: 31,455 m^2
Year: 2010 — 2011
Budget: €4.127.161

The Passeig de Sant Joan Boulevard project is a significant urban revitalization project located in Barcelona, Spain, completed in 2011. Designed by the architecture firm LOLA DOMENECH, in collaboration with the city of Barcelona. The project focuses on the transformation of the Passeig de Sant Joan Boulevard, a prominent avenue in the city, into a vibrant and pedestrian-friendly public space.

The goal was to create a more sustainable and attractive urban environment that encourages social interaction, improves mobility, and enhances the overall quality of life for residents and visitors. The revitalization project involved various interventions to reimagine the boulevard. One of the key features is the expansion of pedestrian areas, with wider sidewalks and dedicated spaces for outdoor seating, recreational activities, and greenery. The project also incorporates bicycle lanes to promote alternative modes of transportation and reduce reliance on cars.

The design of the boulevard prioritizes green infrastructure, with the integration of trees, shrubs, and other vegetation along the sidewalks and median strips. These green elements not only enhance the aesthetics of the boulevard but also provide shade, improve air quality, and mitigate the urban heat island effect. The project serves as a successful example of how thoughtful urban design and the integration of green infrastructure can transform a busy thoroughfare into a sustainable and people-centered space. It showcases the potential for revitalizing urban areas to enhance the well-being of residents, promote sustainable mobility, and create a more livable urban environment.

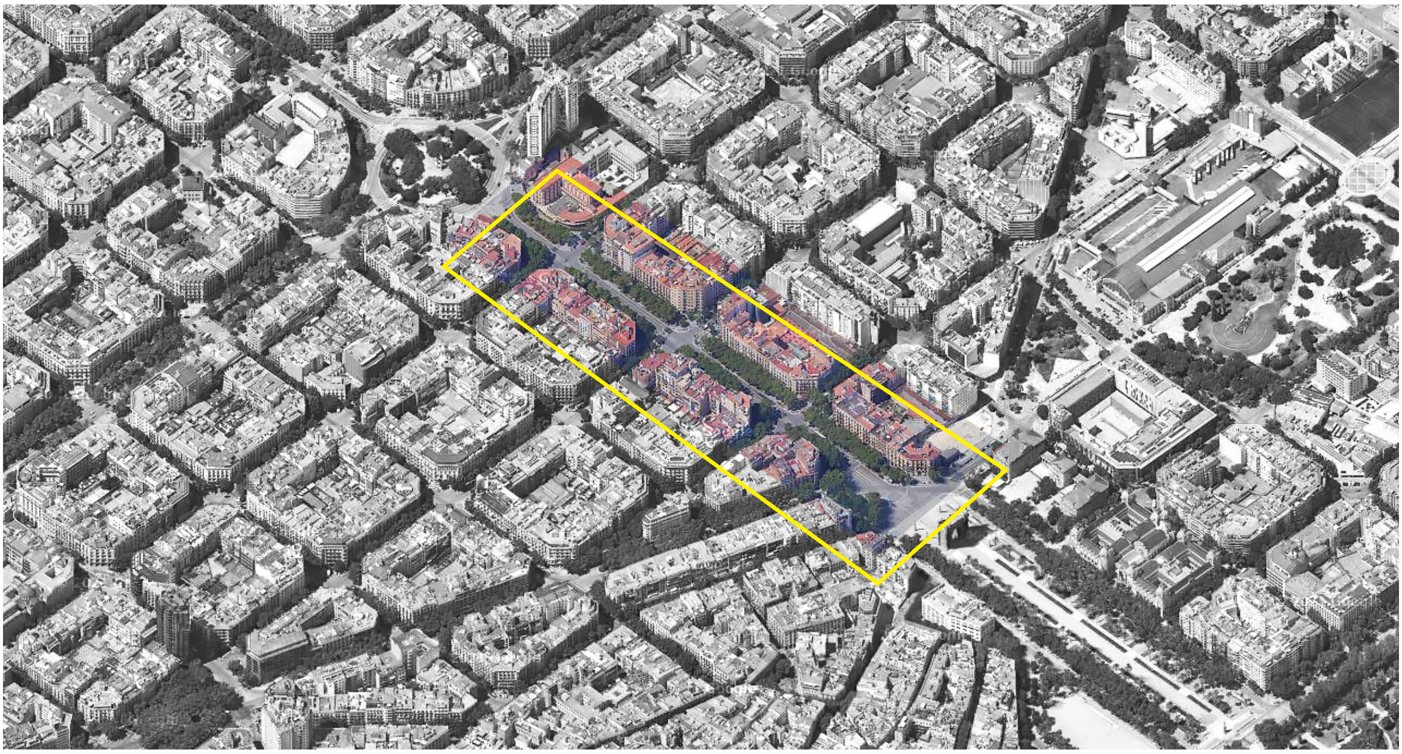


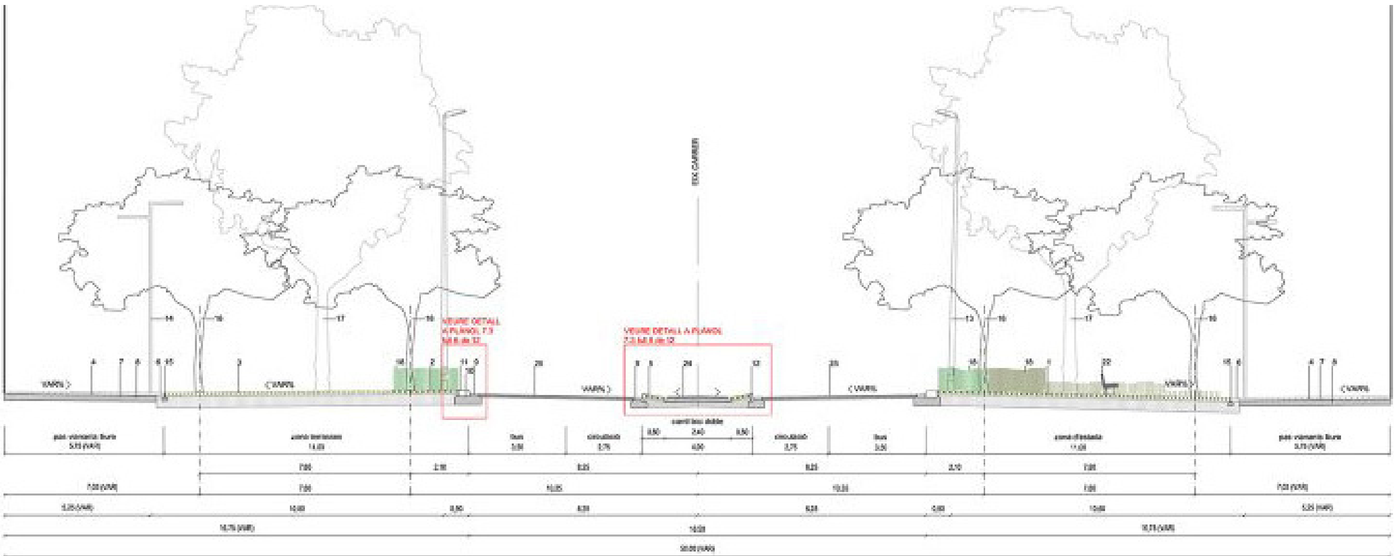
Figure 32: Site location (Developed by the author)

Figure 33: St Joan Boulevard after redesign.
Source: Source: https://www.loladomenech.com/en/project/remodelling-pass
eig-de-st-joan-boulevard-arc-de-triomf-tetuan-square-barcelona/

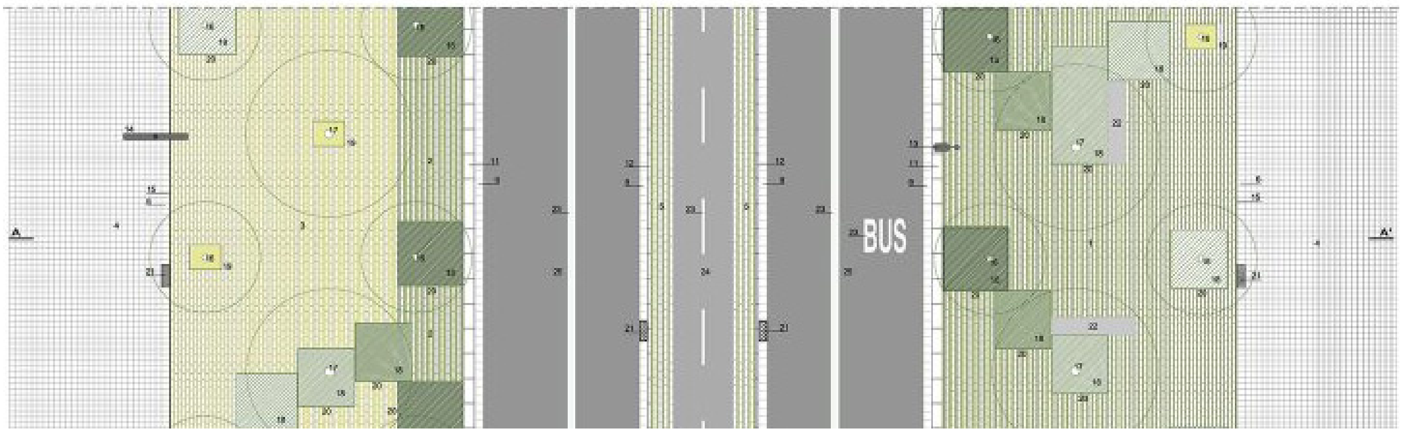
Figure 34: St Joan Boulevard after redesign.
Source: Google maps image

Figure 35: After the intervention
Source: Google map image

Section



Section



Plan

Figure 36: St Joan Boulevard plan and section
Source: https://landezine.com/passeig-de-st-joan-boulevard-by-lola-domenech/

5.2 The Social Spine SLA

Location: Copenhagen, Denmark
Size: 1,470 m^2
Year: 2021 – 2022

The Social Spine by SLA Copenhagen is an innovative urban regeneration project that transformed Scandinavia's largest student housing complex into a vibrant green social spine. The project aimed to rejuvenate the formerly uninspiring and monotonous concrete environment, creating a lively and sustainable community space.

The Social Spine is a pedestrian-oriented spine that runs through the heart of the student housing complex. It serves as a multi-functional gathering space, connecting different buildings and providing a platform for social interaction and community engagement. The once barren and uninviting space has been transformed into a lush green corridor, featuring a variety of trees, plants, and greenery. The design of The Social Spine incorporates various elements that enhance the overall livability and sustainabilityof the space. The use of green infrastructure helps to mitigate the urban heat island effect, improving the microclimate and providing a more comfortable environment for residents and visitors. The inclusion of native plant species promotes biodiversity and contributes to the ecological value of the area, rainwater harvesting systems and permeable paving to manage stormwater runoff and reduce the environmental impact.

One of the key aspects of The Social Spine is its role in fostering a sense of community and belonging among the residents. The vibrant and green gathering spaces provide opportunities for socializing, studying, and hosting events. The inclusion of flexible spaces allows for various activities and functions, accommodating the diverse needs and interests of the student population.

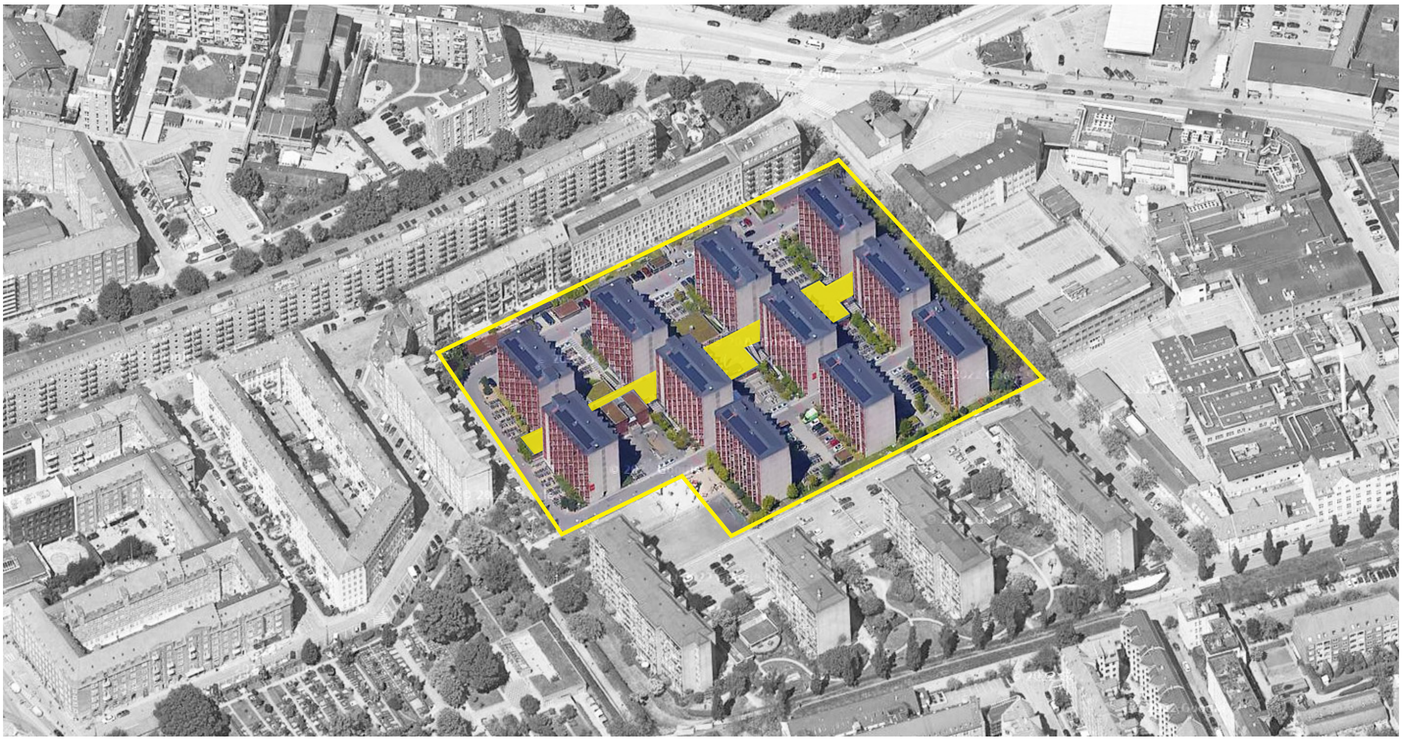


Figure 37: Site location
Source: Developed by the author

Figure 38: The grey line (Before the intervention)
Source: Developed by the author

Figure 39: The grey line (After the intervention)
Source: https://www.sla.dk/news/the-social-spine-wins-the-scandinavian-green-roof-award-2022/

Figure 40: Axonometry of the intervention
Source: https://www.sla.dk/news/the-social-spine-wins-the-scandinavian-green-roof-award-2022/

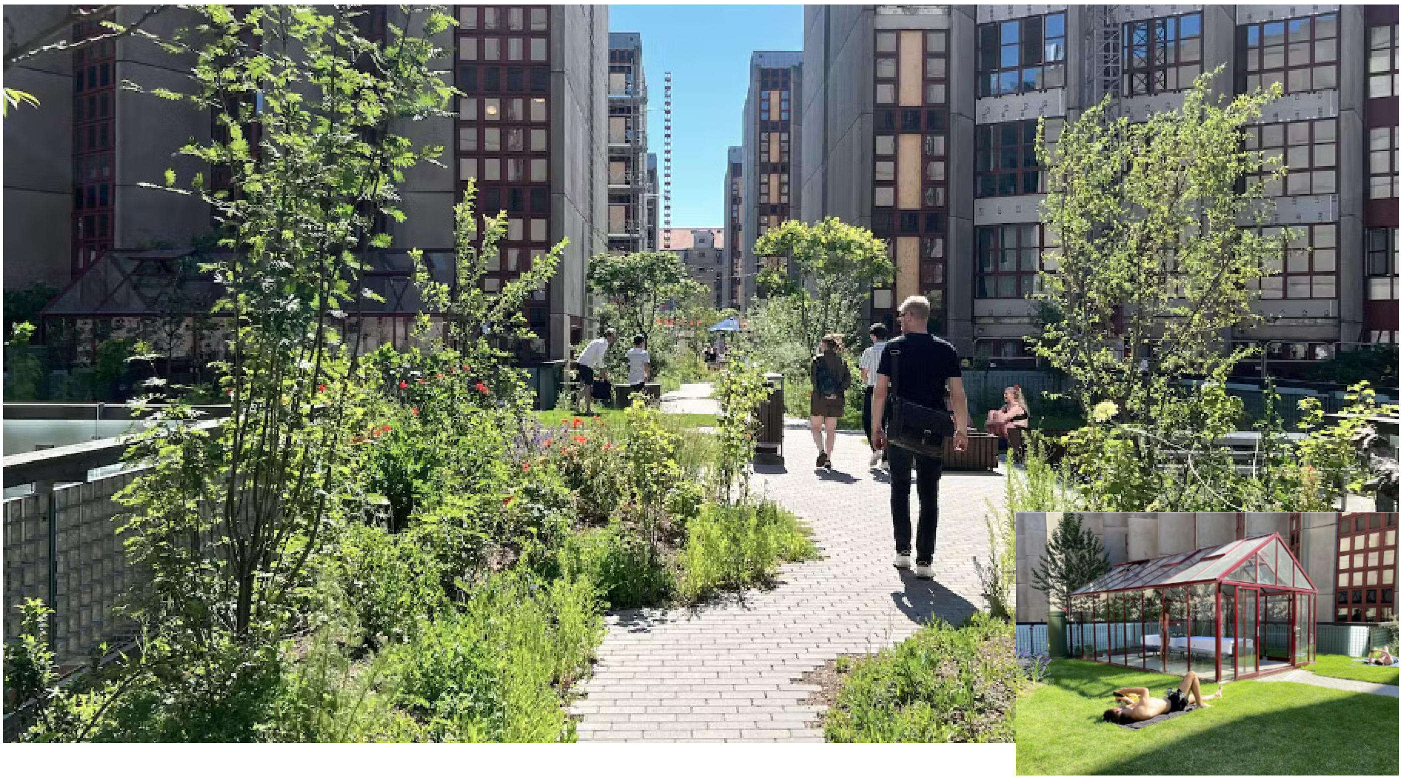


Figure 41: The grey line (After)
Source: https://www.sla.dk/news/the-social-spine-wins-the-scandinavian-green-roof-award-2022/

5.3 Bosco Verticale, Boeri Studio

Location: Milan, Italy
Size: 29,300 m^2
Year: 2007 — 2014

Located in the Porta Nuova district of Milan, Italy, the Bosco Verticale consists of two residential towers: Tower E and Tower F. Rising to heights of 110 and 76 meters respectively, these towers stand as iconic symbols of green architecture. What sets them apart is the extensive greenery that adorns their facades, balconies, and terraces, transforming them into vibrant ecosystems.

The primary aim of the Bosco Verticale is to reintroduce nature into the urban environment and mitigate the ecological footprint of high-density urban living. The towers are home to over 900 trees and 2,000 plants, which together create a remarkable vertical forest equivalent to more than 10,000 square meters of traditional flat land. The selection of vegetation includes a variety of trees, shrubs, and flowering plants carefully chosen for their ability to thrive in an urban setting. The greenery serves multiple purposes beyond aesthetics. It helps filter air pollutants, reduce dust, and absorb carbon dioxide, improving the overall air quality of the surrounding area. The plants also act as a natural barrier, reducing noise pollution and providing shade to regulate temperature, which contributes to energy efficiency by reducing the need for excessive air conditioning or heating.

The design of the Bosco Verticale incorporates sustainability features at various levels. The buildings utilize a sophisticated irrigation system that collects and filters rainwater, ensuring efficient water usage for the plants. Solar panels are installed on the rooftops, harnessing renewable energy to power the towers and reduce their environmental impact.

Figure 42: Site location
Source: Developed by the author

Figure 43: Bosco verticale
https://www.stefanoboeriarchitetti.net/project/bosco-verticale/

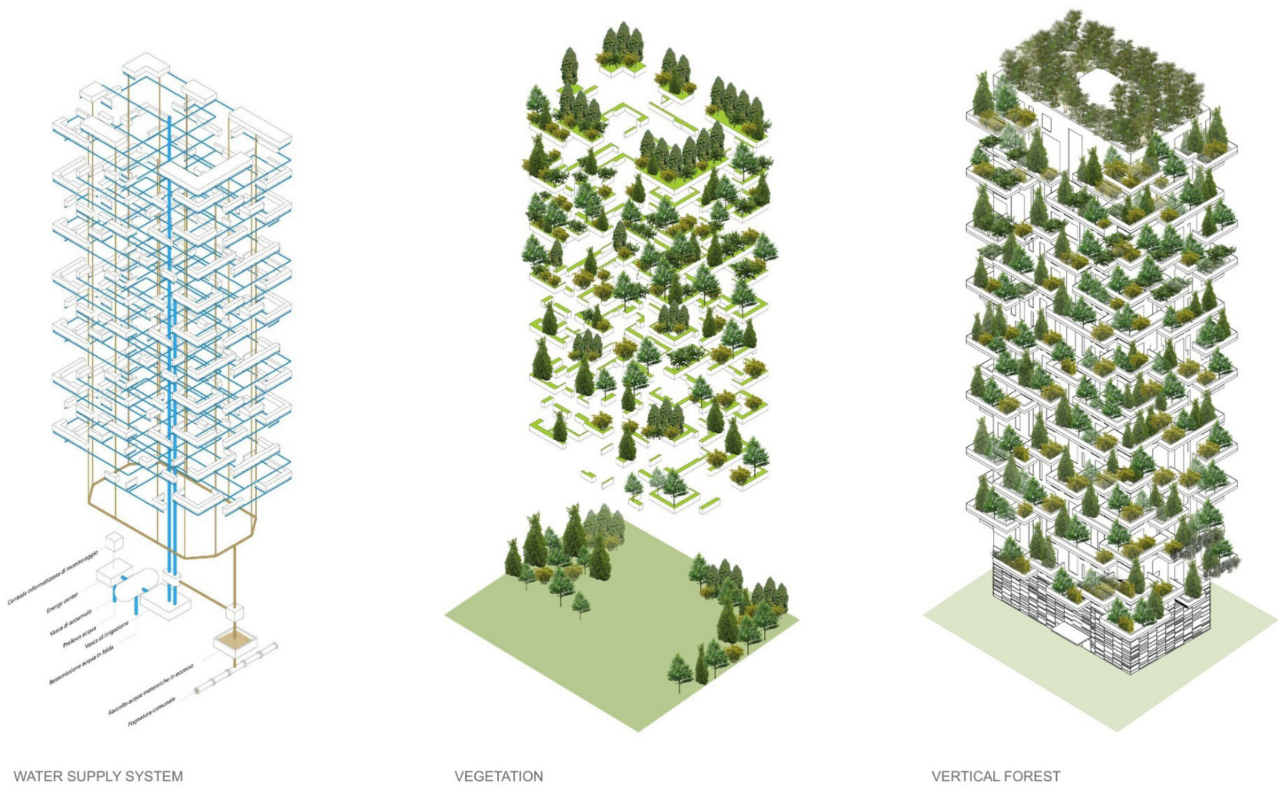


Figure 44: Water supply system, vegetation, vertical forest
https://www.stefanoboeriarchitetti.net/project/bosco-verticale/

Plans

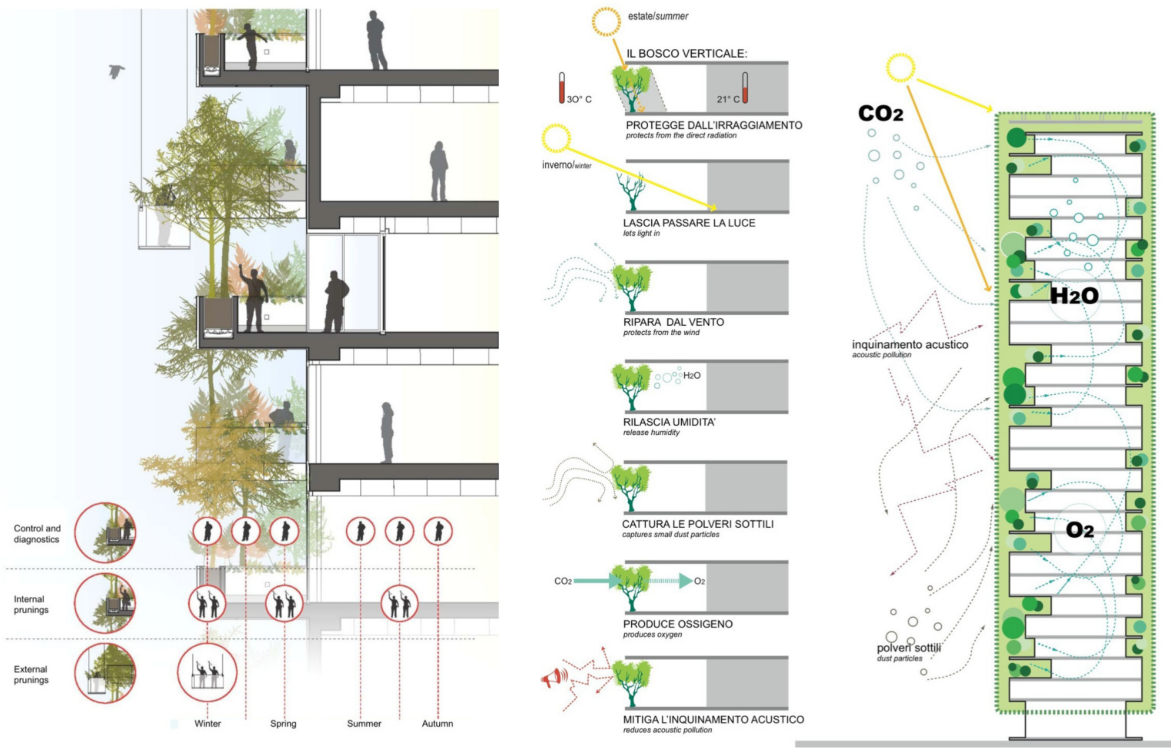


Figure 45: Plans and sections
https://www.stefanoboeriarchitetti.net/project/bosco-verticale/

Sections

5.4 Villa M / Triptyque Architecture

Location: Montparnasse, Paris, France
Size: 8000 m^2
Year: 2021

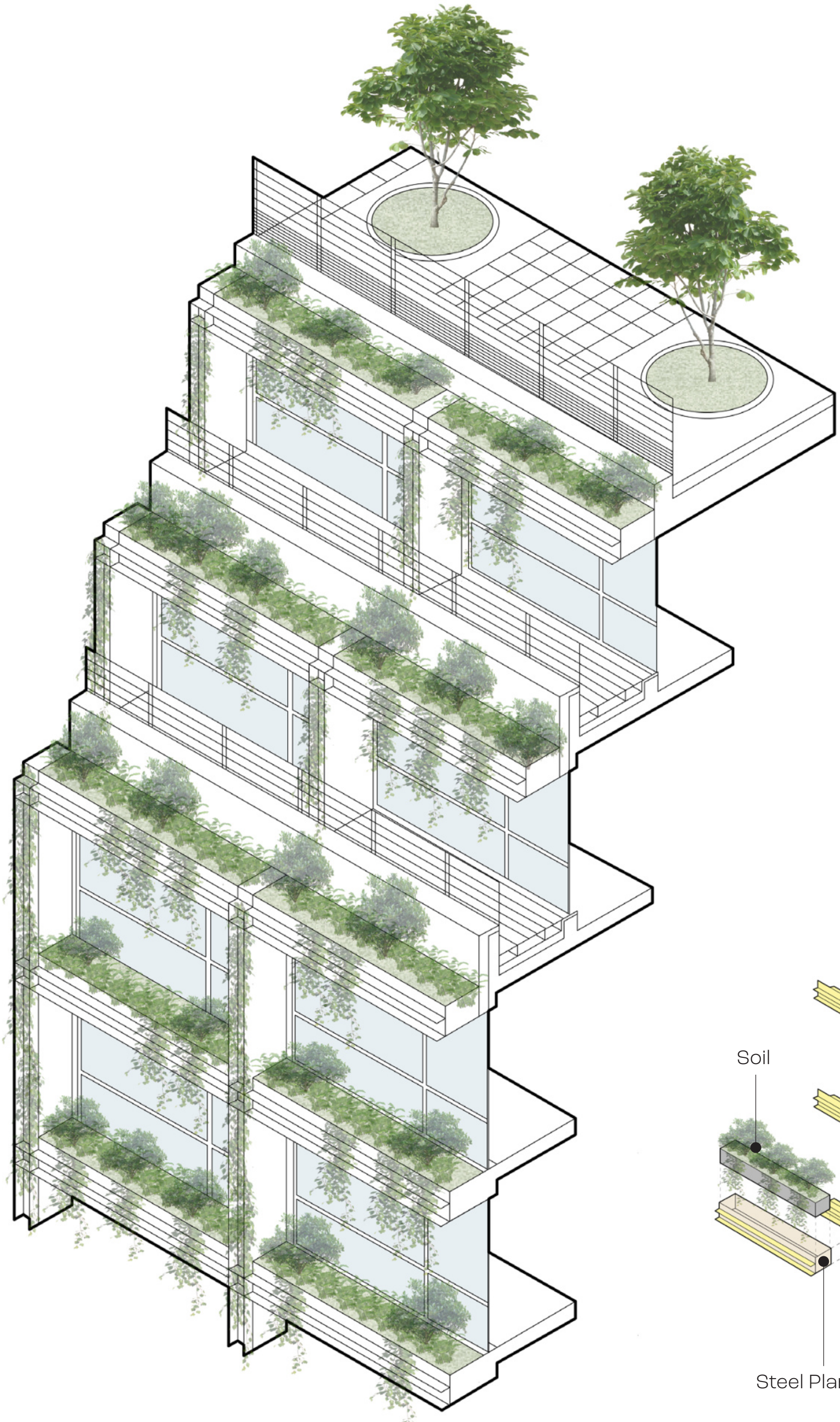
Conceived as a “medical village” and a dynamic center focused on health, Villa M is set to redefine the urban experience and create a harmonious pact between urban life, nature, and well-being. The vision behind Villa M is to transform the building into a living vertical garden that spans the entire façade, creating a medicinal forest in the heart of the city. The ground floor of Villa M features public spaces accessible to all, including a bar, a restaurant, and the “Art & Santé” gallery.The ground floor of Villa M features public spaces accessible to all, including a bar, a restaurant, and the “Art & Santé” gallery. The first level houses a showroom designed for healthcare start-ups, promoting collaboration, exchange, and support among different medical specialties and generations of health professionals. It also includes a coworking space.

On the second level, medical clinics and spaces dedicated to prevention are available to members of the mutual insurance group. Additional facilities include a gym, health paths, a conference room, and three meeting rooms located on the first underground level. Between the third and seventh levels, Villa M accommodates 73 hotel rooms ranging in size from 17 to 45 square meters. These rooms are uniquely characterized by the presence of medicinal plants, creating an ever-changing and vibrant atmosphere throughout the year. The vertical garden that thrives within the thickness of the building’s facade contributes to a sense of openness and protection within the interior spaces. The hotel rooms, designed under the artistic direction of Philippe Starck, exude a warm and welcoming ambiance, incorporating warm colors, natural finishes, and furnishings that evoke a domestic atmosphere, albeit temporary.

Figure 46: Site location
Developed by the author

Figure 47: Facade
https://triptyque.com/en/project/villa-m-en/

Figure 48: Axonometry
https://triptyque.com/en/project/villa-m-en/



The facade acts as a filter between the interior and the exterior, featuring a vertical garden supported by a dark steel exoskeleton designed to accommodate vegetation in specially designed planters with integrated irrigation systems. From the second to the fifth levels, the facade showcases a sequence of steel tanks finished in harmony with the supporting structure. These tanks house stainless steel planters that can be easily removed for maintenance. The irrigation system is discreetly integrated within the structural exoskeleton, while ropes within the outer profiles support the climbing vegetation. The downpipe system is cleverly concealed within the cavity of the vertical load-bearing elements, ensuring it remains hidden from view.

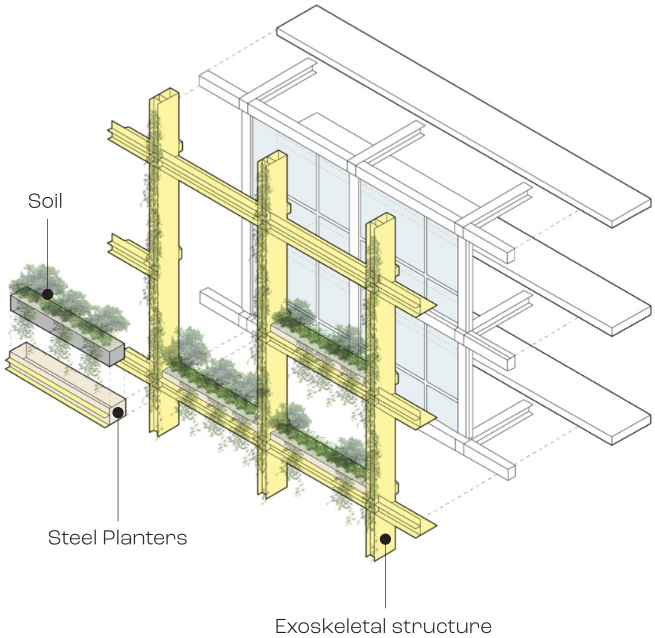


Figure 49: Facade Axonometry (redrawned by the author)
Source: https:/https://triptyque.com/en/project/villa-m-en/

Figure 50: Exploded Axonometry (redrawned by the author)
Source:https://triptyque.com/en/project/villa-m-en/

5.5 Capella Garcia: Green Side-Wall

Location: Barcelona, Spain
Size: 288 m^2
Year: 2009 — 2011
Budge:€216,397

The Green Side-Wall is a remarkable vertical garden and plant support structure developed as an integrative intervention to address the negative visual impact left by the demolition of an old building, which exposed a party wall visible from the street. The structure itself is a free-standing metal framework supported by an independent foundation. It runs parallel to the façade of an existing building, gradually narrowing as it rises to a height of 21 meters. One notable feature that sets this project apart from other vertical greenery installations is the convenience of interior access to the plants. Unlike traditional structures that require exterior access for maintenance and replanting, the Green Side-Wall provides a more accessible and cost-effective solution.

This convenience is made possible by integrating interior steps, simplifying the process and reducing the need for specialized labor. Furthermore, the living surface of the green façade undergoes continuous transformation, serving as a protective barrier against external elements. It offers cooling during the summer months, thermal insulation in winter, and acts as a natural filter by generating oxygen, absorbing CO2, and reducing pollution.

Additionally, it functions as an acoustic screen, effectively dampening noise and enhancing the overall environmental quality. The entire structure is constructed using prefabricated galvanized steel components that are assembled on-site. The platforms on each level are made of galvanized expanded metal, providing stability and durability.

Figure 51: Site location
Developed by the author

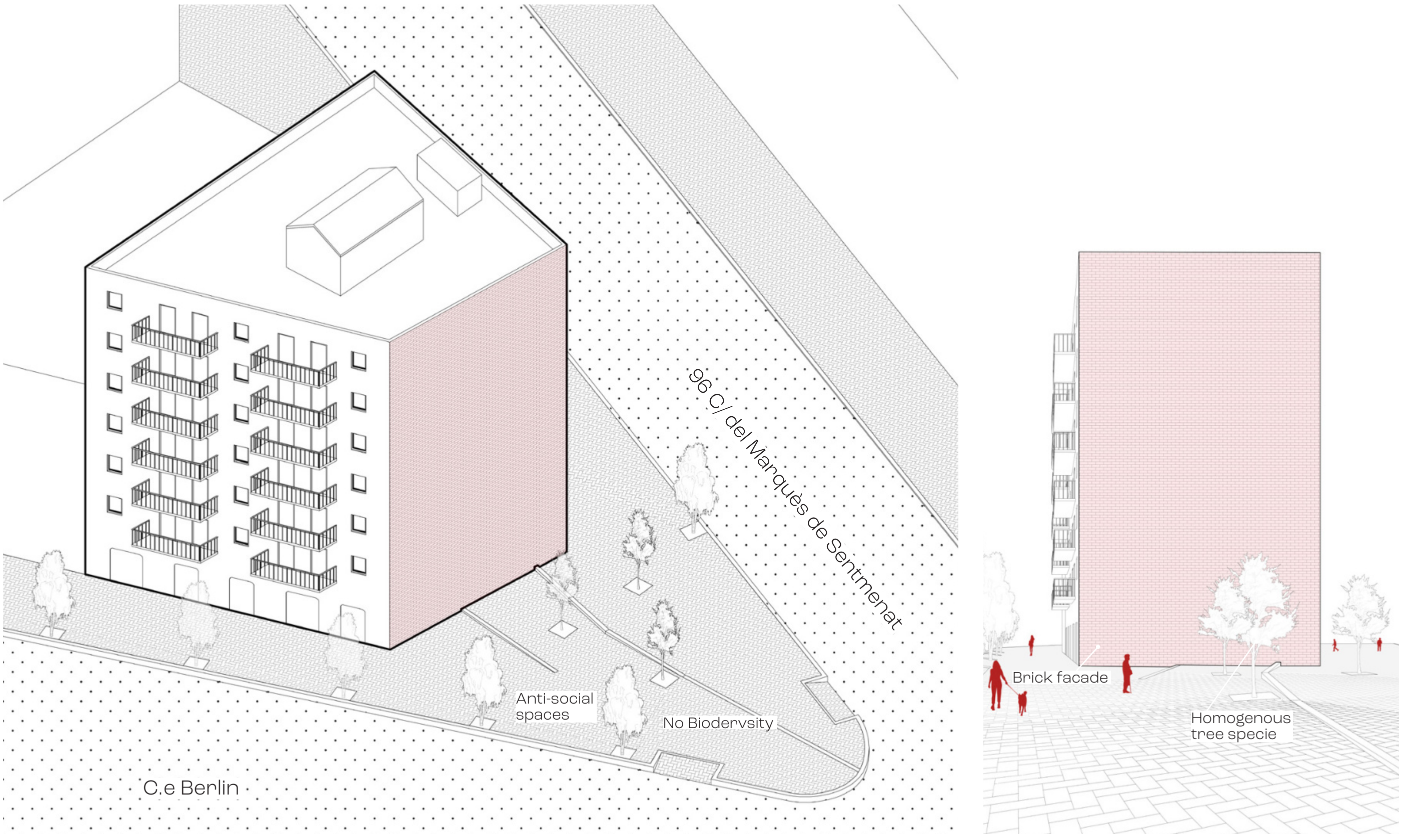


Figure 52: Before the intervention (Developed by the author)

Figure 53: Green wall and public space
Source: Capella Garcia Arquitectura

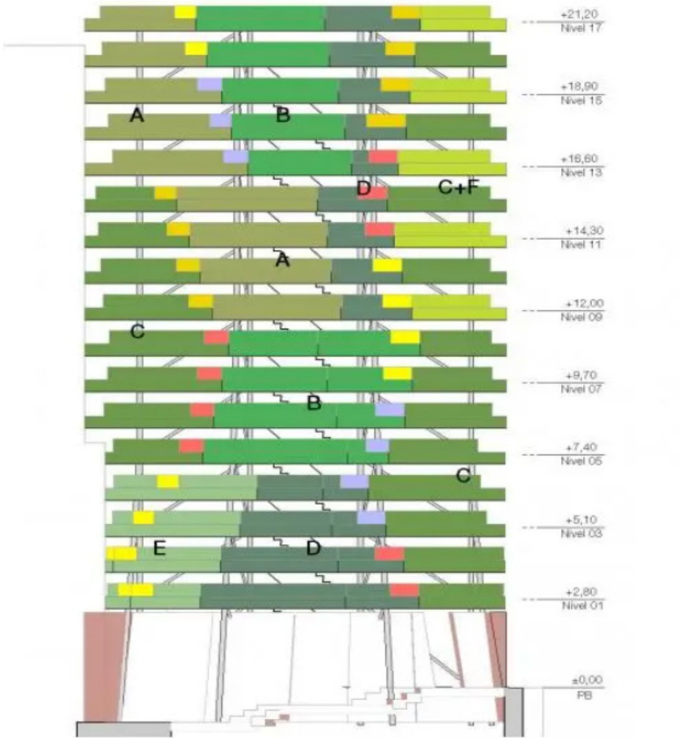


Figure 54: Vegetation scheme
Source: Capella Garcia Arquitectura

Base plantings

- A Muehlenbeckia complexa
- B Hedera Helix
- C Ficus pumila
- D Jasminum polyanthum
- E Viburnum tinus
- F Parthenocissus quinquefolia

Secondary plantings

- Aptenia
- Plumbago
- Elaeagnus
- Sedum

Figure 55: Prefabricated galvanished steel structure
Source: Capella Garcia Arquitectura

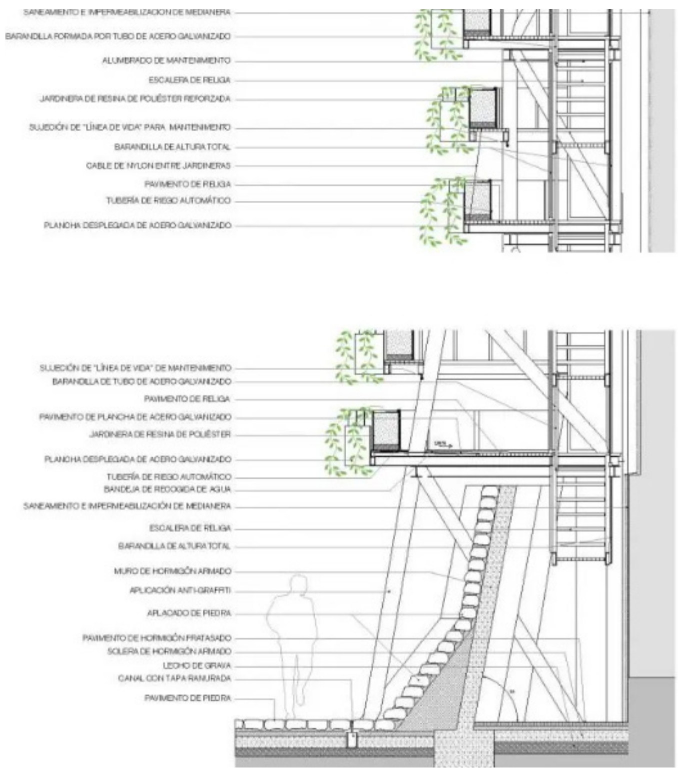


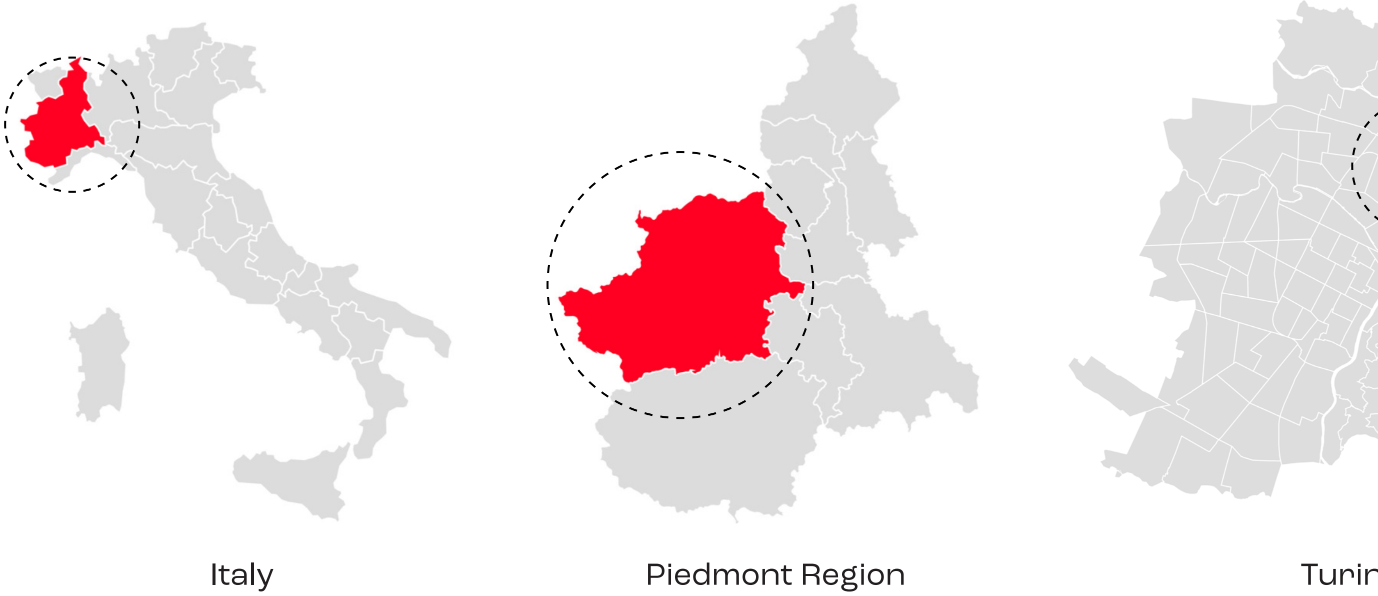
Figure 56: Construction detail
Source: Capella Garcia Arquitectura

Figure 57: Green wall
Capella Garcia Arquitectura

CHAPTER 6
ENVIRONMENTAL REGENERATION PROJECT

T OF QUARTIERE S1 NEIGHBORHOOD

Figure 58: Site Location
Source:Developed by the author



Why Regio Parco?

1. Historical Significance
The neighborhood's historical roots, including its association with a royal residence, offer a unique backdrop for studying the transformation of a historically rich area.

2. Industrial Legacy
Regio Parco's industrial legacy, marked by the Tobacco Factory and Vanzina Spinning Mill, provides insights into the environmental impact of past industrial practices. Examining the environmental repercussions of industrialization informs strategies for remediating and regenerating former industrial zones.

3. Demographic Diversity
The multicultural composition of residents, including Romanians, Moroccans, Chinese, and Peruvians, presents a diverse demographic canvas.
A diverse population offers a comprehensive understanding of how green infrastructure can cater to varied cultural and social needs.


Cimitero Monumentale di Torino
Source: Google Map


Parco Pietro Colletta
Source: Google Map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Source: Google Map


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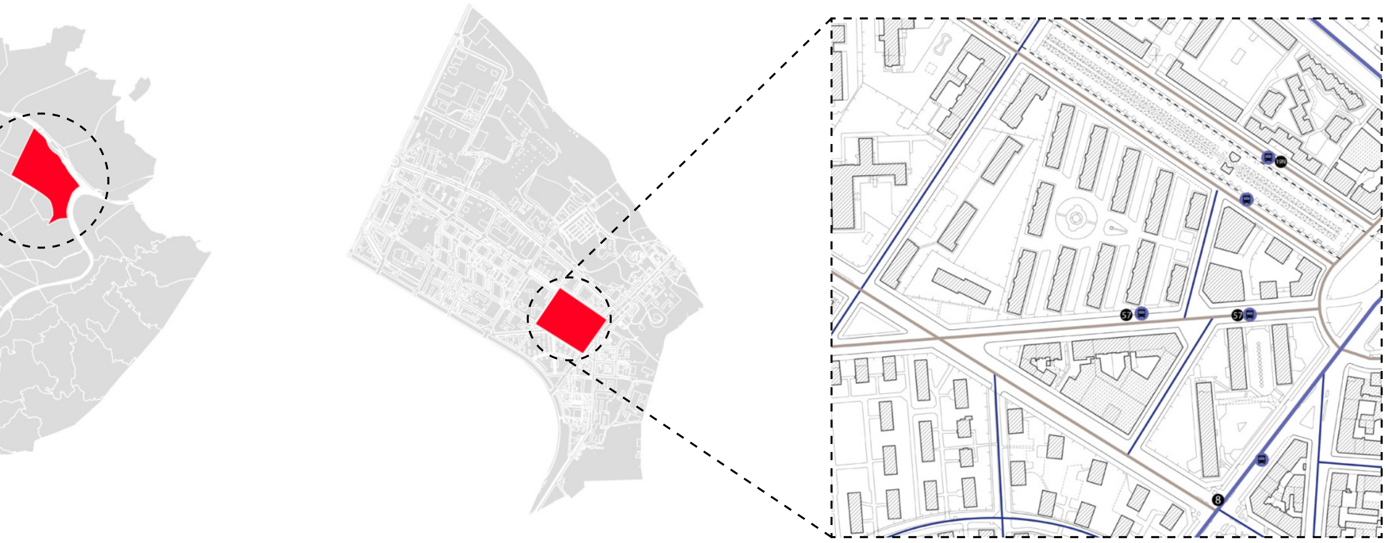

n

Regio Parco

Area of intervention

4. Social Housing Influence
The prevalence of social housing indicates a commitment to inclusivity and affordability in residential planning. The influence of social housing on community dynamics can be explored to gauge the impact of green initiatives on residents from different socio-economic backgrounds.

5. Preservation of Heritage
The Quartiere S1, a preserved post-war social housing complex, exemplifies the community's commitment to preserving historical and architectural heritage. Studying this preservation effort informs strategies for integrating green spaces without compromising historical significance.

6. Urban Transformation Initiatives
Ongoing urban transformation plans, as per the P.R.G., reveal a commitment to reshaping the neighborhood for a more sustainable future. Investigating planned changes provides an opportunity to incorporate green infrastructure into urban design and assess its potential impact on the area.

anifatttura Tabacchi
ource: Google Map

Basilica di Superga
Source: Author

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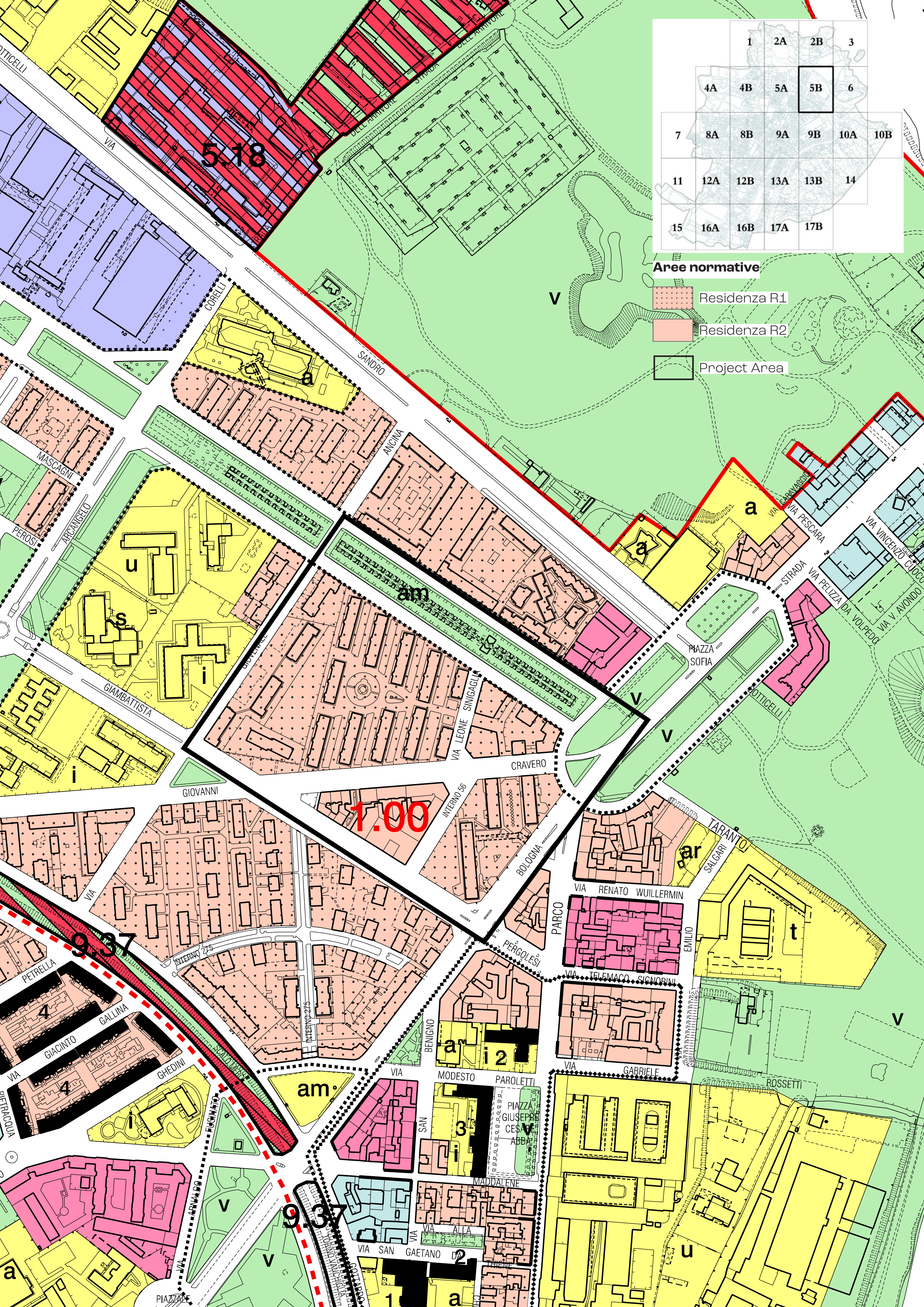
Source: Toninocronaca.it

Chiesetta di Legno
Source: Google Map


Aree normative
Residenza R1
Residenza R2
Project Area
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PIAZZA SOFIA
VIA GIOVANNI CRAVERO
VIA LEONE SINIGAGLIA
INTERNO 56
VIA BOLOGNA
VIA GIAMBATTISTA GIOVENALE
VIA RENATO WUILLERMIN
VIA TELEMACO SIGNORINI
VIA GABRIELE ROSSETTI
PARCO
EMILIO SALGARI
TARANTO
VIA PELIZZA DA VOLPEDO
VIA PESCARA
VIA CARAVAGGIO
VIA VINCENZO CUOCO
VIA V. AVONDO
VIA MODESTO PAROLETTI
VIA SAN BENIGNO
PIAZZA GIUSEPPE CESARE ABBA
MADDALENE
VIA SAN GAETANO DA THIENE
VIA ALLA
INTERNO 275
PERGOLESI
ANCINA
CORELLI
MASCAGNI
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ARCANGELO
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TITOLO II – ZONE E AREE NORMATIVE:
CLASSIFICAZIONE, REGOLE E PARAMETRI DI TRASFORMAZIONE

Art. 8 – Aree normative: classificazione e destinazioni d'uso
Per le zone normative vengono individuate le destinazioni d'uso ammesse secondo le definizioni dell'art.3 con la precisazione che le attività di servizio pubblico di cui al punto 7 del succitato art.3 sono consentite in tutte le aree normative.

Le aree normative, individuate nelle tavole di piano in scala 1:5.000, sono:

1. Area R1

1. Residenze realizzate prevalentemente con piani o progetti unitari.

2. La destinazione è residenziale (v. art.3 punto 1A).
Al piano interrato, terreno e primo sono consentite le attività commerciali al dettaglio di cui all'art. 3 punti 4A1a e 4A1b1 nei limiti e nel rispetto di quanto disposto nell'allegato C, attività per la ristorazione e pubblici esercizi (v. art. 3 punto 4A2), attività artigianali di servizio (v. art. 3 punto 4A3), studi professionali, agenzie bancarie, assicurative, immobiliari, ecc. (v. art.3 punto 5A) ed a tutti i piani le attività ricettive (v. art.3 punto 2A).

3. I fabbricati realizzati con piani attuativi unitari sono riconfermati nella consistenza quantitativa esistente (SLP) indipendentemente dall'indice di densità fondiaria della zona normativa in cui ricadono. Fatti salvi gli interventi oggetto di specifici progetti del Quartiere 37 nell'ambito del Programma di Recupero Urbano di corso Grosseto.

È consentito incrementare e modificare l'uso del piano interrato, terreno e primo degli edifici con le attività elencate all'art.3 punti 4A1a, 4A1b1, 4A2, 4A3 e 5A purché tali interventi non comportino la chiusura dei piani a pilotis. Fatti salvi gli interventi oggetto di specifici progetti del Quartiere 37 nell'ambito del Programma di Recupero Urbano di corso Grosseto.
Gli interventi di sostituzione edilizia devono essere coerenti con l'impianto originario e devono integrarsi con il contesto urbano circostante.

4. I fabbricati non realizzati con strumenti urbanistici esecutivi, di cui al precedente capoverso, seguono i parametri di trasformazione urbanistici ed edilizi della zona normativa di appartenenza.

5. I fabbricati aventi tipologia a ville (evidenziati nelle tavole di piano con asterisco) hanno parametri edilizi propri riportati nella tavola normativa relativa alle zone di appartenenza.

6. I parcheggi devono essere realizzati in sottosuolo.

2. Area R2

7. Isolati residenziali a cortina edilizia verso spazio pubblico.

8. La destinazione è residenziale (v. art.3 punto 1A).
Al piano interrato, terreno e primo sono consentite le attività commerciali al dettaglio di cui all'art. 3 punti 4A1a e 4A1b1 nei limiti e nel rispetto di quanto disposto nell'allegato C, attività per la ristorazione e pubblici esercizi (v. art. 3 punto 4A2), attività artigianali di servizio (v. art 3 punto 4A3), studi professionali, agenzie bancarie, immobiliari, ecc. (v. art.3 punto 5A) e a tutti i piani gli usi ricettivi (v. art.3 punto 2A).

9. I parametri di trasformazione urbanistici ed edilizi da rispettare sono quelli della zona normativa di appartenenza (v. Tav. normative).

10. Le aree interne agli isolati, contestualmente a interventi di completamento, nuovo impianto e ristrutturazione urbanistica, devono essere liberate e riqualificate per formare spazi di verde privato.

11. I parcheggi devono essere realizzati in sottosuolo; sono ammessi parcheggi in cortina edilizia con esclusione delle zone storico ambientali.

Piano Regolatore Generale (English Translation)

TITLE II - ZONING AND REGULATORY AREAS:
CLASSIFICATION, RULES, AND TRANSFORMATION PARAMETERS

Art. 8 - Regulatory Areas: Classification and Land Use Designations

For regulatory zones, permitted land use designations are identified according to the definitions in Article 3, with the clarification that public service activities mentioned in point 7 of the aforementioned Article 3 are allowed in all regulatory areas.

The regulatory areas, identified in the 1:5,000 scale plan tables, are:

1. Area R1

1. Residences predominantly realized with unified plans or projects.
2. The designation is residential (see Article 3, point 1A).
3. Retail commercial activities are allowed in the basement, ground, and first floors, as per Article 3, points 4A1a and 4A1b1, within the limits and in compliance with Annex C. Also allowed are restaurant and public establishment activities (see Article 3, point 4A2), artisanal service activities (see Article 3, point 4A3), professional studios, banking agencies, insurance, real estate, etc. (see Article 3, point 5A). Accommodations are permitted on all floors Article 3, point 2A).

4. Buildings realized with unified implementing plans maintain their existing quantitative consistency (GLA) regardless of the land use density index of the regulatory area. This is subject to specific projects of District 37 within the Urban Recovery Program of Corso Grosseto.
5. It is allowed to increase and modify the use of the basement, ground, and first floors of buildings with activities listed in Article 3, points 4A1a, 4A1b1, 4A2, 4A3, and 5A, provided these interventions do not involve the closure of pilotis floors. This is subject to specific projects of District 37 within the Urban Recovery Program of Corso Grosseto.

6. Replacement building interventions must be consistent with the original layout and integrate with the surrounding urban context.

2. Area R2

7. Residential blocks with building facades facing public spaces.
8. The designation is residential (see Article 3, point 1A).

9. Retail commercial activities are allowed in the basement, ground, and first floors, as per Article 3, points 4A1a and 4A1b1, within the limits and in compliance with Annex C. Also allowed are restaurant and public establishment activities (see Article 3, point 4A2), artisanal service activities (see Article 3, point 4A3), professional studios, banking agencies, real estate, etc. (see Article 3, point 5A). Accommodations are permitted on all floors (see Article 3, point 2A).

9. Transformation parameters, both urbanistic and building, must adhere to those of the respective regulatory area (see Regulatory Table).

10. Internally within blocks, simultaneous with completion, new installations, and urban restructuring interventions, areas must be cleared and redeveloped to form private green spaces.

11. Parking must be constructed underground; parking in building facades is allowed, excluding historic environmental zones.

Art.12 – Zone urbane consolidate residenziali miste

1. Il piano definisce "zone urbane consolidate" l'insieme delle aree edificate con precedenti piani nelle quali si individua l'esigenza di migliorare la qualità urbana e la dotazione dei servizi.

Le zone consolidate residenziali miste sono individuate nelle tavole di piano in scala 1:5000.

2. Nella parte piana gli indici di densità fondiaria sono pari a 2 mq/mq.; 1,35 mq/mq.; 1 mq/mq.; 0,6 mq/mq.; 0,4 mq/mq.

3. I parametri di trasformazione urbanistici ed edilizi sono riportati nelle tavole normative. I fili stradali generati dall'apertura di nuove strade, sia pubbliche che private, all'interno di aree normative, costituiscono a tutti gli effetti filo edilizio di fabbricazione obbligatorio.

4. Per gli edifici di particolare interesse storico e per gli edifici caratterizzanti il tessuto storico vigono le norme di tutela ed i tipi di intervento particolari riportati all'art. 26 e descritti nell'allegato A.

5. Il piano si attua attraverso autorizzazioni o concessioni singole. Gli interventi di ristrutturazione urbanistica, nuovo impianto e sostituzione che richiedono la creazione di nuove opere di urbanizzazione od il coordinamento di operatori pubblici e privati per la realizzazione delle stesse si attuano mediante concessione convenzionata ex art. 49 comma 5 della L.U.R. con le modalità di cui all'art. 6 delle presenti norme.

6. Le zone urbane consolidate sono classificate di categoria B secondo il D.M. 02.04.68 n. 1444, di completamento ai sensi dell'art. 13 comma 3 lettera f) della LUR e di recupero ai sensi della legge 457/78.

Article 12 - Consolidated Mixed Residential Urban Zones

1. The plan defines "consolidated urban zones" as the set of built-up areas with previous plans where there is a need to improve urban quality and service provision.

Consolidated mixed residential zones are identified in the 1:5000 scale plan tables.

2. In the flat part, land density indices are 2 sq/m; 1.35 sq/m; 1 sq/m; 0.6 sq/m; 0.4 sq/m.

3. Urbanistic and building transformation parameters are detailed in the regulatory tables. Street lines generated by the opening of new roads, both public and private, within regulatory areas, constitute mandatory building lines.

4. For buildings of particular historical interest and those characterizing the historical fabric, protection norms and specific intervention types as detailed in Article 26 and described in Annex A apply.

5. The plan is implemented through individual authorizations or concessions. Urban restructuring, new installations, and replacement interventions requiring the creation of new urbanization works or the coordination of public and private operators for their realization are carried out through a concession agreement under Article 49, paragraph 5 of the L.U.R., with the modalities outlined in Article 6 of these regulations.

6. Consolidated urban zones are classified as category B according to D.M. 02.04.68 no. 1444, completion under Article 13, paragraph 3, letter f) of the LUR, and recovery under the provisions of Law 457/78.

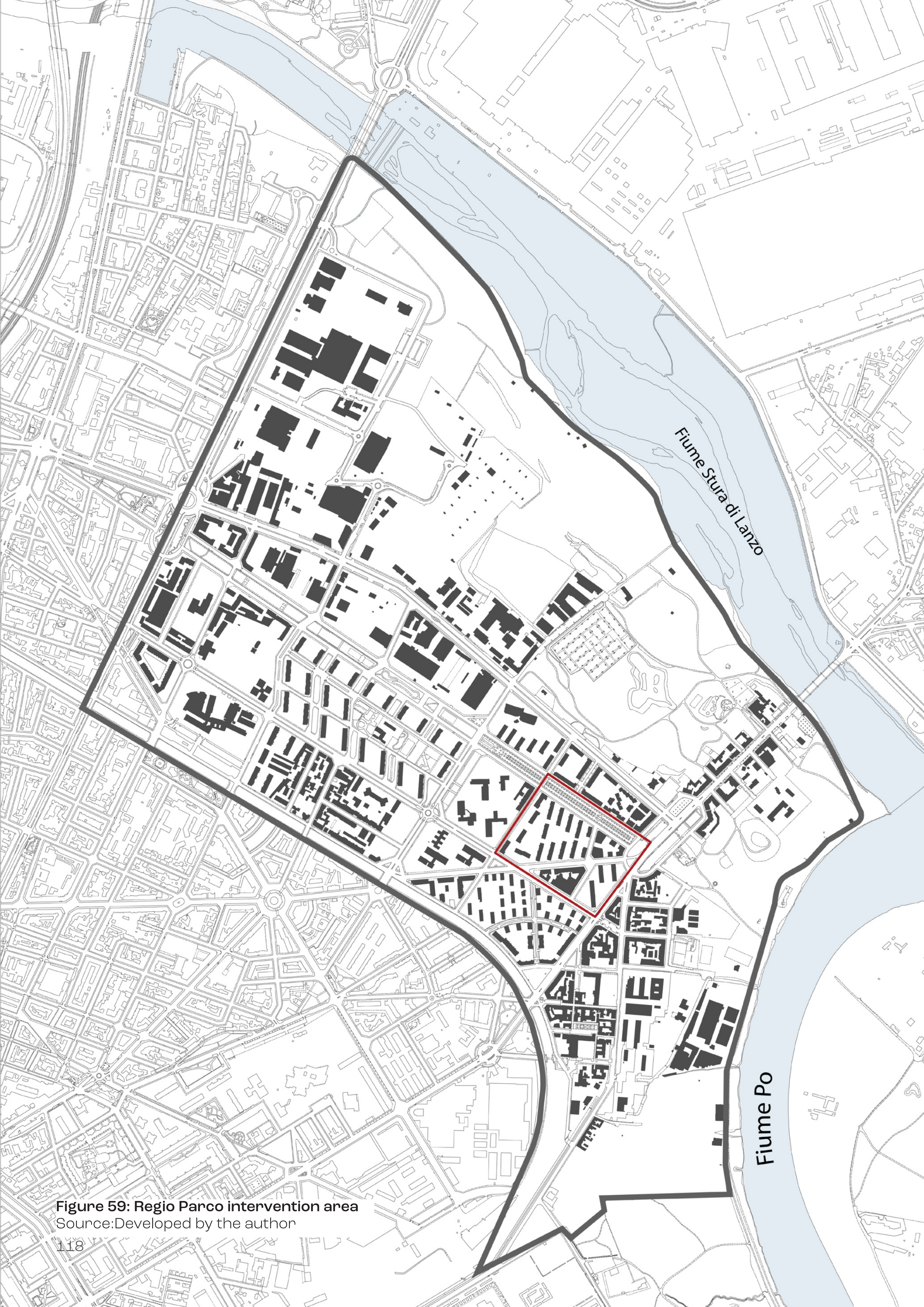


Figure 59: Regio Parco intervention area
Source:Developed by the author

BRIEF STORY OF REGIO PARCO

Regio Parco is a historically significant neighborhood located in the Sixth District of the Municipality of the city of Turin, Italy. Its boundaries are defined by Colletta Park, the Po River, the Stura di Lanzo Torrent, Corso Giulio Cesare, Via Gottardo, Corso Mamiani, and Corso Regio Parco. The neighborhood encompasses various streets and squares, including Corso Taranto, Maddalene, Parco Colletta, Piazza Derna, Piazza Sofia, Via Botticelli, Via Gottardo, and Via Pergolesi. Regio Parco dates back to the 16th century when it was used as a park by the House of Savoy. At that time, there stood the Viboccone Castle, which was later transformed into the Palace of Delights. The castle was known for its architectural beauty, featuring frescoes by the painter Guglielmo Caccia. The area was used for various "logistic and ecological" services related to the Royal Park estate. However, the castle was destroyed by the French during the siege of Turin in 1706. The name "Regio Parco" is a reminder of the former Royal Park and the extensive pleasure residences in the area. In the 18th century, after the destruction of the Royal Park and the Palace of Delights, the land was left abandoned. In 1829, the monumental cemetery of Turin was built on the former park grounds. Simultaneously, the Royal Tobacco Factory was constructed in 1758, reflecting the state's control over tobacco processing.

Regio Parco is known for its vibrant culture, with a population that includes artists, designers, professionals, and students. It is a bright and lively neighborhood, with natural features like the Dora River and green pedestrian avenues that add to the quality of life. Additionally, it is only a 12-minute walk to Piazza Castello in the city center. The neighborhood has gone through redevelopment efforts in recent years, making it a valuable addition to the city's architectural and cultural landscape. The neighborhood is home to a public housing district with approximately 5,000 inhabitants, built in the late 1960s. Residents have been actively engaged in seeking improved living conditions and services, leading to the establishment of the Local Promotion Group (GPL) "United for the neighborhood" in 1998. The GPL focuses on promoting participation, identifying actions for physical and social recovery, and enhancing local resources.

Relevant Places and Monuments:
- Monumental Cemetery of Turin: Built on the former park grounds, this cemetery is an important landmark in the neighborhood.
- Royal Tobacco Factory: The historical factory, which was a hub for tobacco processing, reflects the neighborhood's industrial past.
- Wooden Church (via Perosi): Originally constructed in 1961, it has been renovated and expanded, serving as a community center for various activities.
- Piazza Tartini: This square has been redeveloped with city funds and is an essential public space in the neighborhood.
- Local Promotion Group (GPL): This organization plays a pivotal role in promoting participation and facilitating the physical and social recovery of the neighborhood.
- Various streets and squares: Regio Parco boasts a network of streets, squares, and avenues that contribute to the neighborhood's character and functionality.

Parocchia Resurrezione del Signore
Source: Google Map

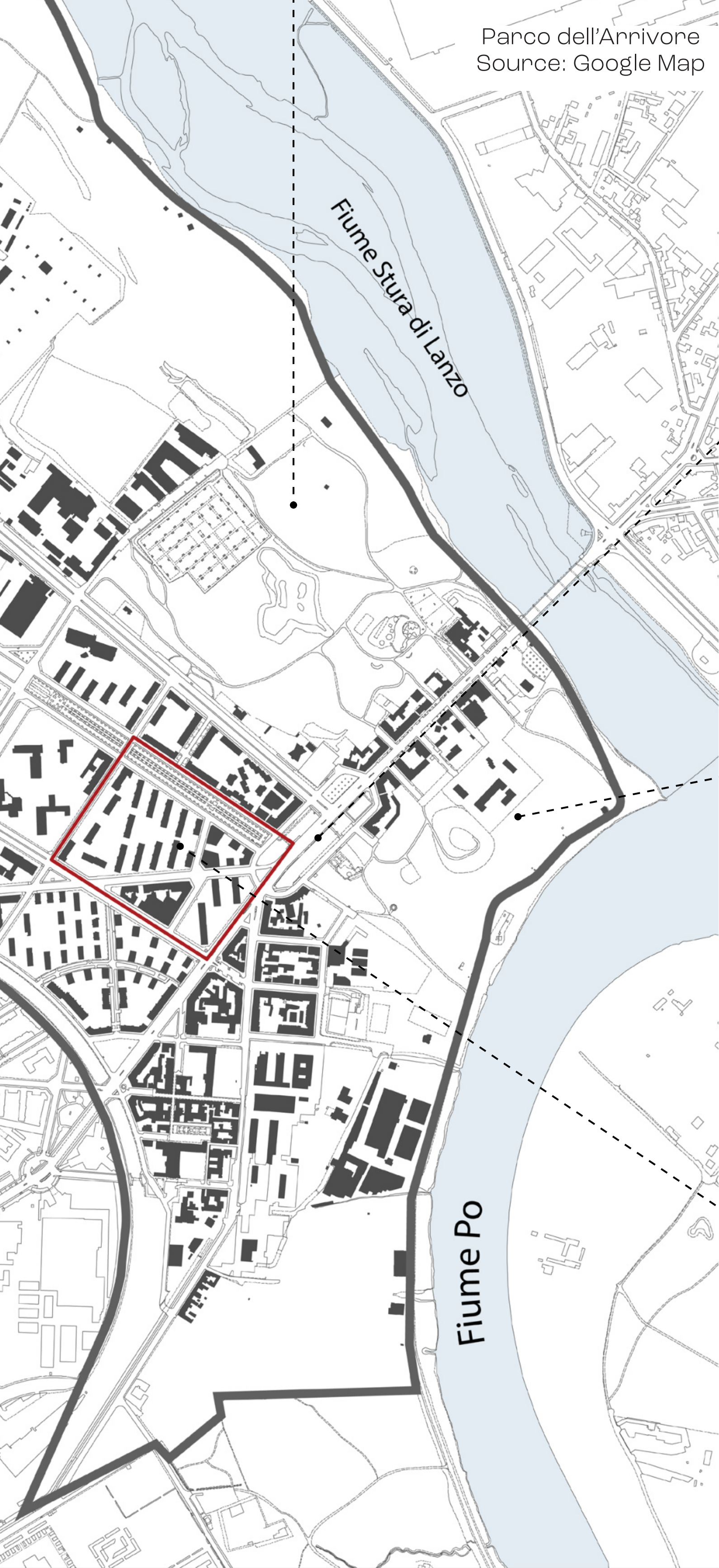
Corso Giulio Cesare
Source: Google Map

Parocchia Resurrezione del
Signore Source: Google Map

Quartiere di corso Tarant0
Source: Google Map

Chiesetta di Legno
Source: Google Map

Figure 60: Territorial analysis
Source:Developed by the author



Parco dell'Arrivore
Source: Google Map

Parcheggio GTT Sofia
Source: Google Map

Piazza Sofia
Source: Google Map

Parco della Confluenza
Source: Google Map

Quartiere S1
Source: Google Map

Quartiere 18° Villaggio rurale
Source: Google Map

L'Asilo Infantile Umberto I
Source: Google Map

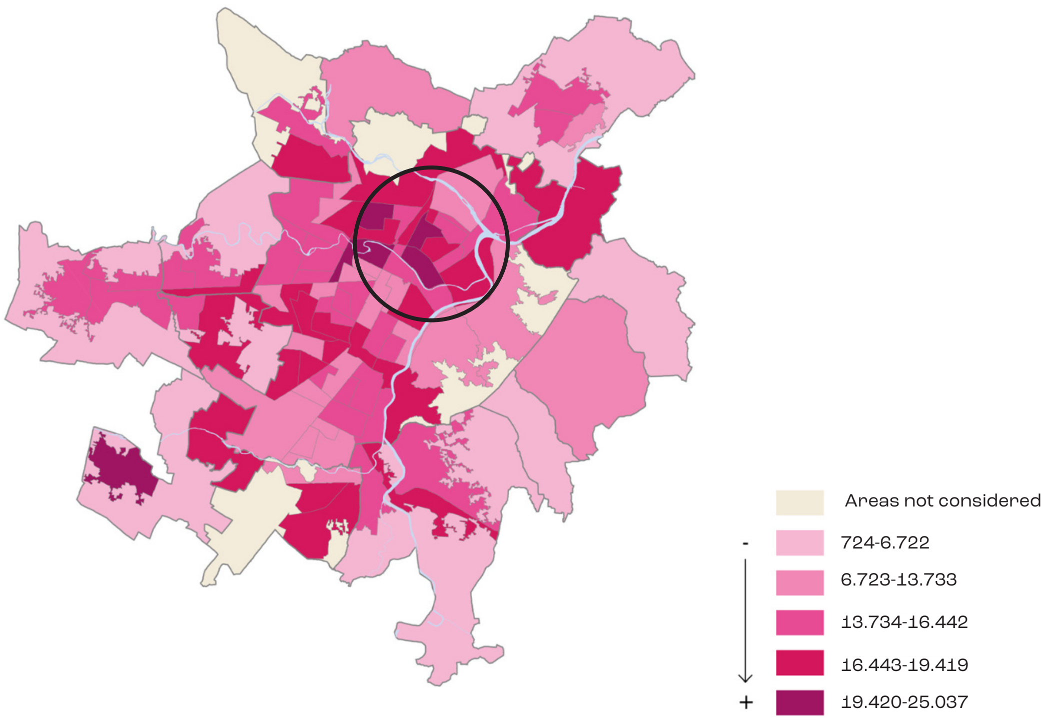
Scuola elemetare G.C.Abba
Source: Google Map

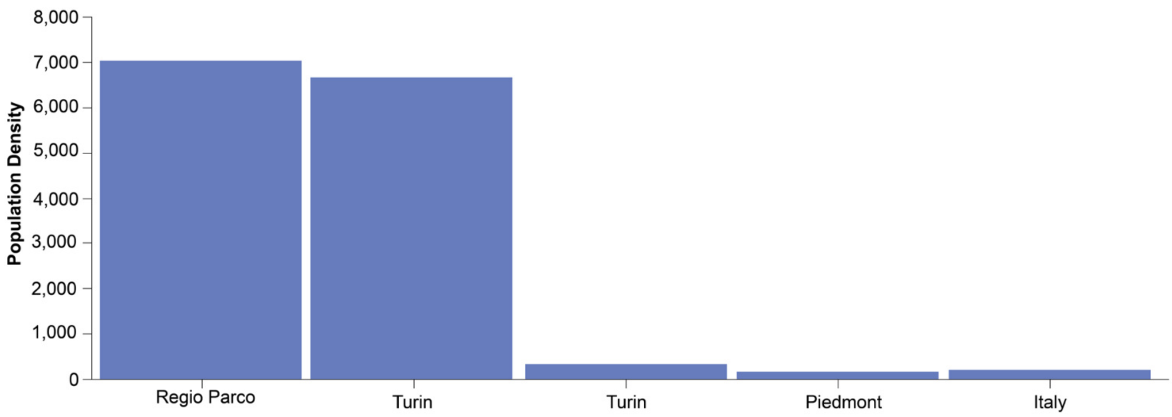
Ex Manifattura Tabacchi
Source: Google Map

Ex Stabilimento FIMIT
Source: Google Map

Chiesa di San Gaetano da Thiene
Source: Google Map

Demographic Analysis:
Source: Torino Atlas, 2018

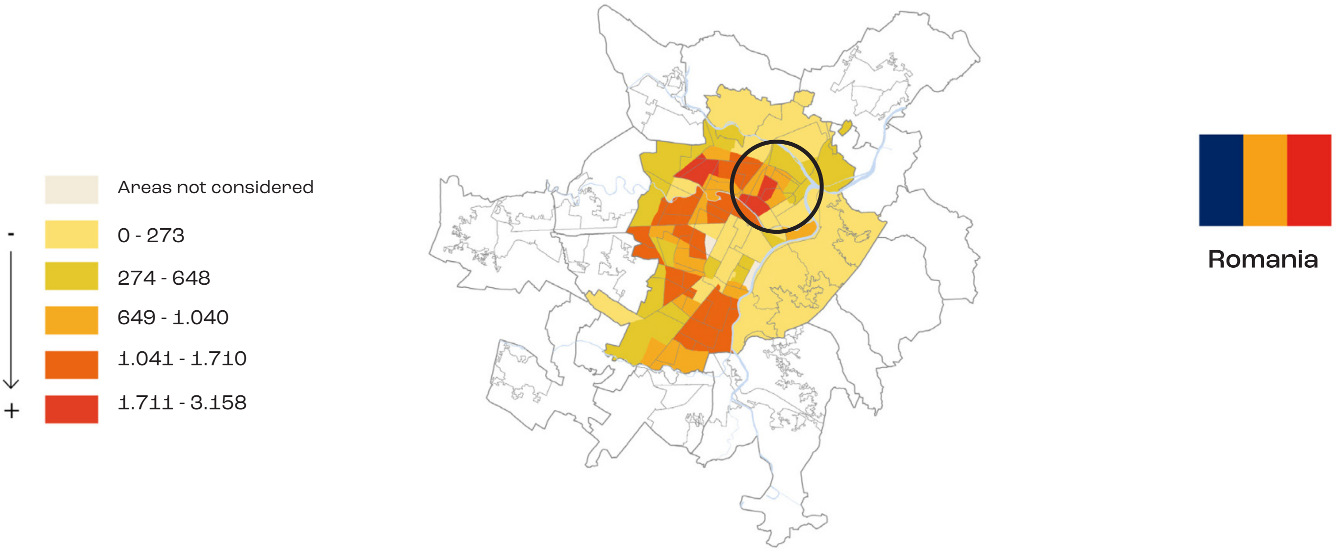


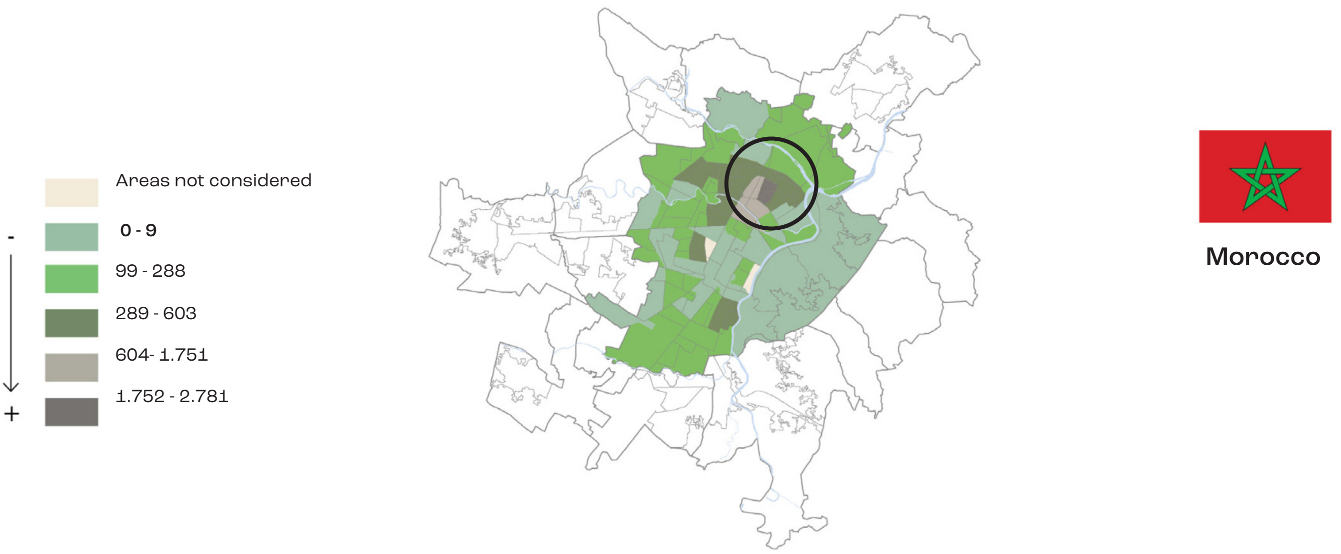


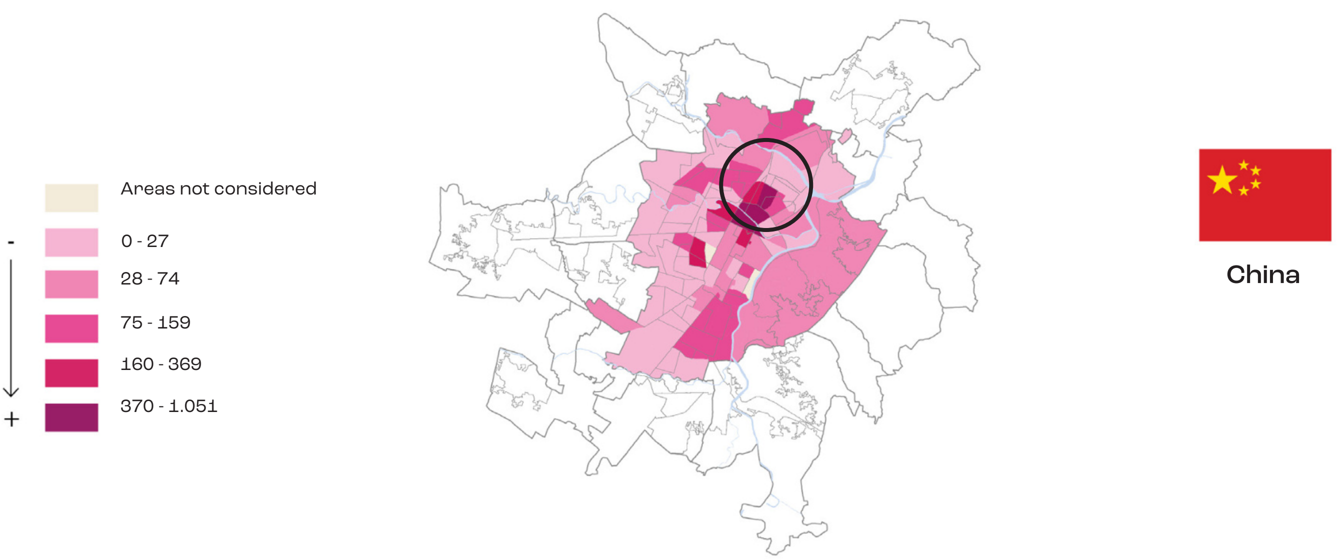
Location	Population	Area	Population Density
Regio Parco, Turin, Piedmont, Italy	19,295	2.728 km²	7,073 / km²
Turin	865,559	130.1 km²	6,651 / km²
Turin	2.3 million	6,332.7 km²	330.1 / km²
Piedmont	4.4 million	25,400.2 km²	172.2 / km²
Italy	59.4 million	302,749.6 km²	196.2 / km²

Demographic Analysis: Main foreign resident groups (2015) absolute values

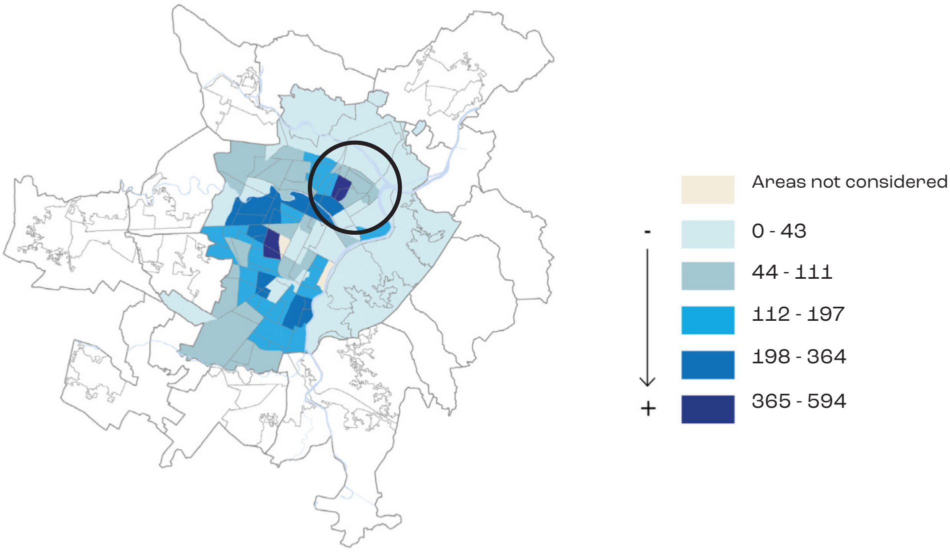
Source: Torino Atlas, 2018







Perù



Main foreign resident groups (2015) absolute values
Source: Torino Atlas, 2018

Regio Parco district, as of the 2018 data from the Torino Atlas, is characterized by a diverse and vibrant population, particularly notable for its significant foreign resident groups. The largest among these are Romanians, suggesting a considerable presence likely influenced by factors such as economic opportunities, historical ties, or established social networks within the district. Following closely are Moroccans, indicating a multifaceted demographic composition shaped by historical migration patterns, economic prospects, or community networks that attract residents of Moroccan origin. Additionally, the Chinese and Peruvian communities contribute to the cosmopolitan nature of Regio Parco, reflecting the district's appeal to a globalized population, possibly drawn by economic activities and diverse opportunities.

The multicultural environment in Regio Parco presents both opportunities and challenges. On one hand, the coexistence of various nationalities fosters a rich cultural tapestry, promoting mutual understanding and cultural exchange. On the other hand, this diversity may pose challenges related to social integration and cohesion, requiring thoughtful policies and community initiatives to ensure that all residents, regardless of their background, can fully participate in and contribute to the district's community life.

The presence of social housing is suggested as a potential factor influencing the demographic composition, emphasizing the importance of housing policies in shaping the population dynamics of the area. In light of these observations, local authorities and community organizations in Regio Parco should consider tailoring policies that address the specific needs and aspirations of the diverse population. Understanding the economic dynamics that attract residents from different backgrounds can inform targeted initiatives that contribute to the well-being of the community.

Figure 61: Intervention area
Source:Developed by the author

NEIGHBOURHOOD

Quartiere di Corso Taranto

Area: 84.217,73 m²

Total Distance: 1,17km

The Quartiere S1 in Turin stands as a testament to the post-World War II era's commitment to addressing housing challenges and improving living conditions for a diverse population. Constructed in 1946, this social housing complex was a response to the pressing need for affordable housing, particularly for those living in inadequate and precarious conditions.
The neighborhood, comprising twelve buildings with entrance porticos overlooking small vegetable gardens, reflects the architectural trends of its time. The layout was meticulously designed to foster a sense of community and incorporate green spaces within the complex, addressing not only the need for housing but also the creation of a livable and interconnected community. Over the years, the Quartiere S1 has undergone expansions and improvements to accommodate a growing population. The initial nine buildings were completed in 1946, with subsequent extensions in 1950 and 1956 as part of the "Fanfani Plan."
Noteworthy interventions in the 1960s involved the demolition of the original core, replaced by condominiums in Via Bologna and Via Gottardo. The community-driven initiatives of the residents, such as the establishment of a nursery school, sports center, shopping center, and a unique prefabricated wooden church, showcase the residents' dedication to enhancing the quality of life in the neighborhood. These services not only improved living conditions but also contributed to the overall social fabric and vibrancy of Quartiere S1.
As a historical and architectural landmark, the Quartiere S1 carries a legacy of post-war urban planning and social housing. Its significance extends beyond its physical structures, embodying the spirit of community engagement and resilience. Preserving its historical and architectural importance has been a priority, showcasing the enduring impact of thoughtful urban planning on the well-being of a neighborhood and its residents. Today, the Quartiere S1 remains an integral part of Turin's social and architectural heritage, a living example of how community-driven initiatives can shape the character and identity of a neighborhood over time.

1 **Figure 62: Public Residential Construction (1965-1966 photo)**
Source:https://www.museotorino.it/view/s/abae-d771171c42b9b37be38db5805499

1 **Figure 63: Public Residential Construction (2023 photo)**
Source:Google Map

2 **Figure 64: Housing Main Entrance**
Source:Google Map

3 **Figure 65: Courtyards situation**
Source:Google Map

4 **Figure 65: Internal mobility A**
Source:Google Map

5 **Figure 66: Internal mobility B**
Source:Google Map

6 **Figure 67: Commercial Block A**
Source:Google Map

7 **Figure 68: Commercial Block B**
Source:Google Map

8 **Figure 69: Corso Taranto**
Source:Google Map

9 **Figure 70: Via Giovanni Cravero**
Source:Google Map

10 **Figure 71: Piazza Sofia**
Source:Google Map

11 **Figure 72: Via Giambattista Pergolesi**
Source:Google Map

12 **Figure 73: Via Giovanni Cravero 56**
Source:Google Map

13 **Figure 74: Via Leone Sinigaglia**
Source:Google Map

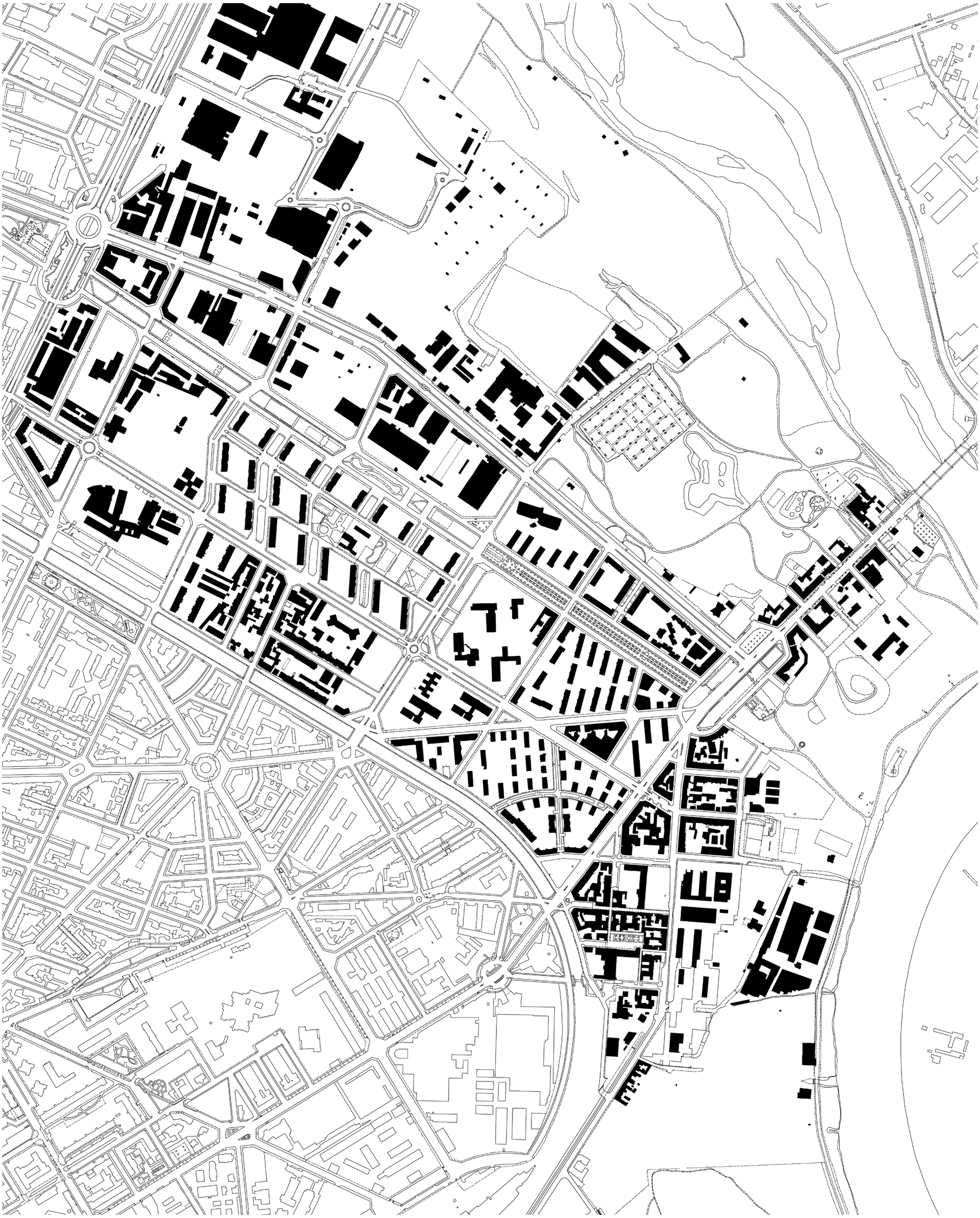


Figure 75: Buiding blocks area density

Scale 1:10000

N

Solid

Voids

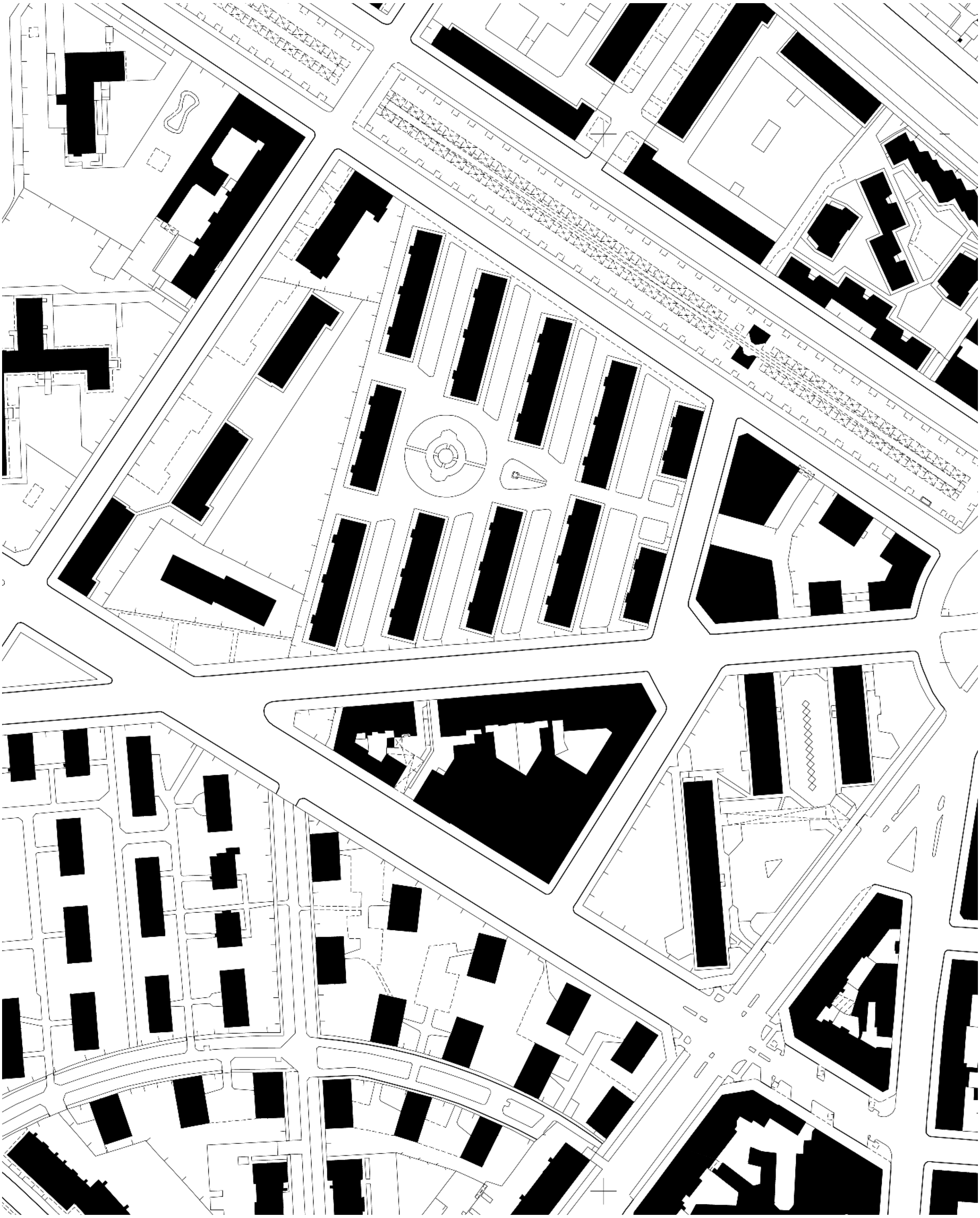


Figure 76: Buiding blocks area density

Scale 1:2000

Solid

Voids

Figure 77: Landuse Map

Scale 1:5000

N

	Mixed use residential/ Commercial		Services
	Residential		Production
	Commercial		Garage/Parking spaces

Figure 78: Green Space

Scale 1:5000

N

	Building Blocks		Services
	Private green		Parks and gardens

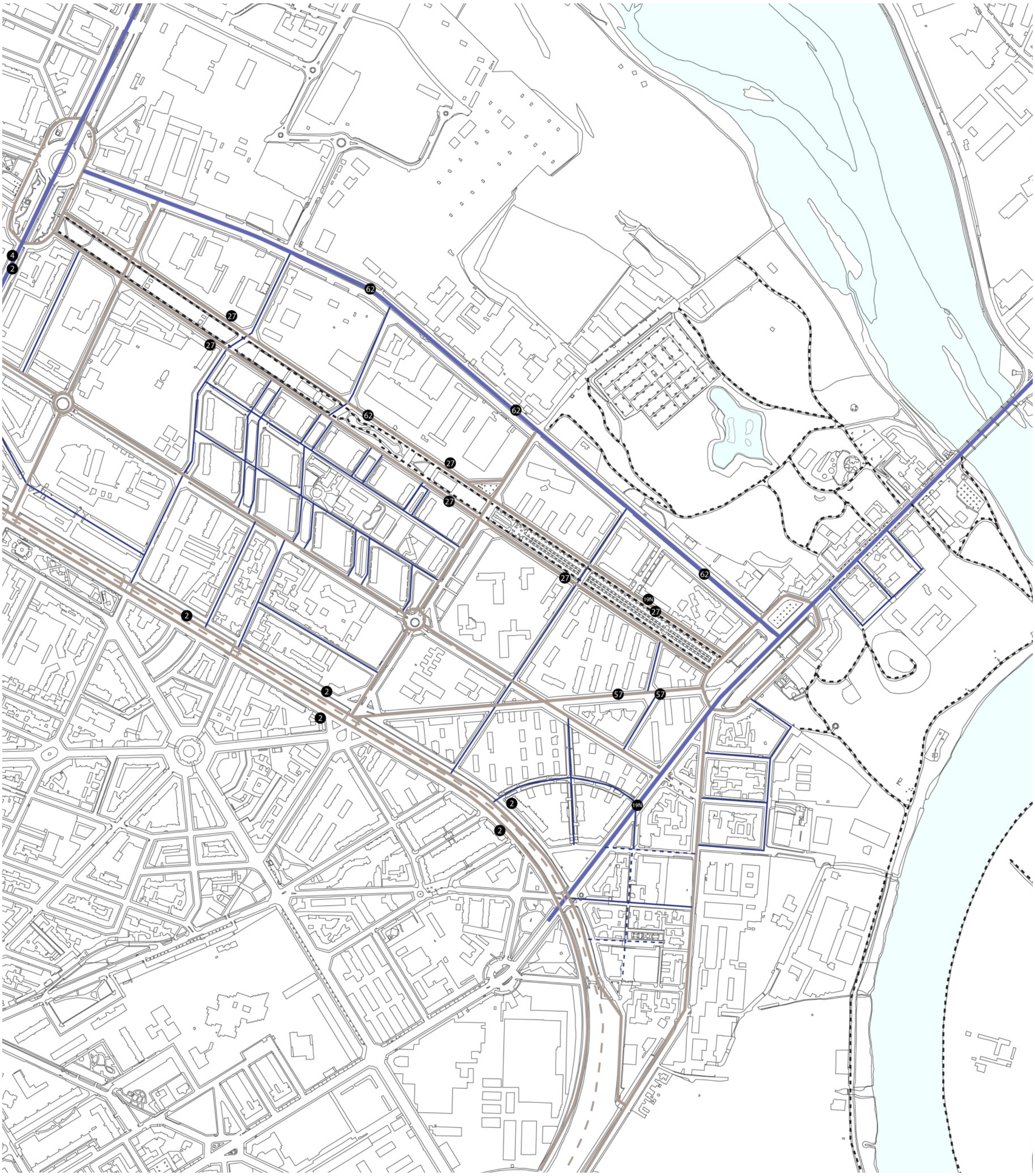


Figure 79: Mobility Map

Scale 1:10000

N

	Primary Network: Urban road		Cycling path
	Secondary Network: Urban distribution road		Former railway link
	Secondary Network: Neighbourhood Street		Former railway link

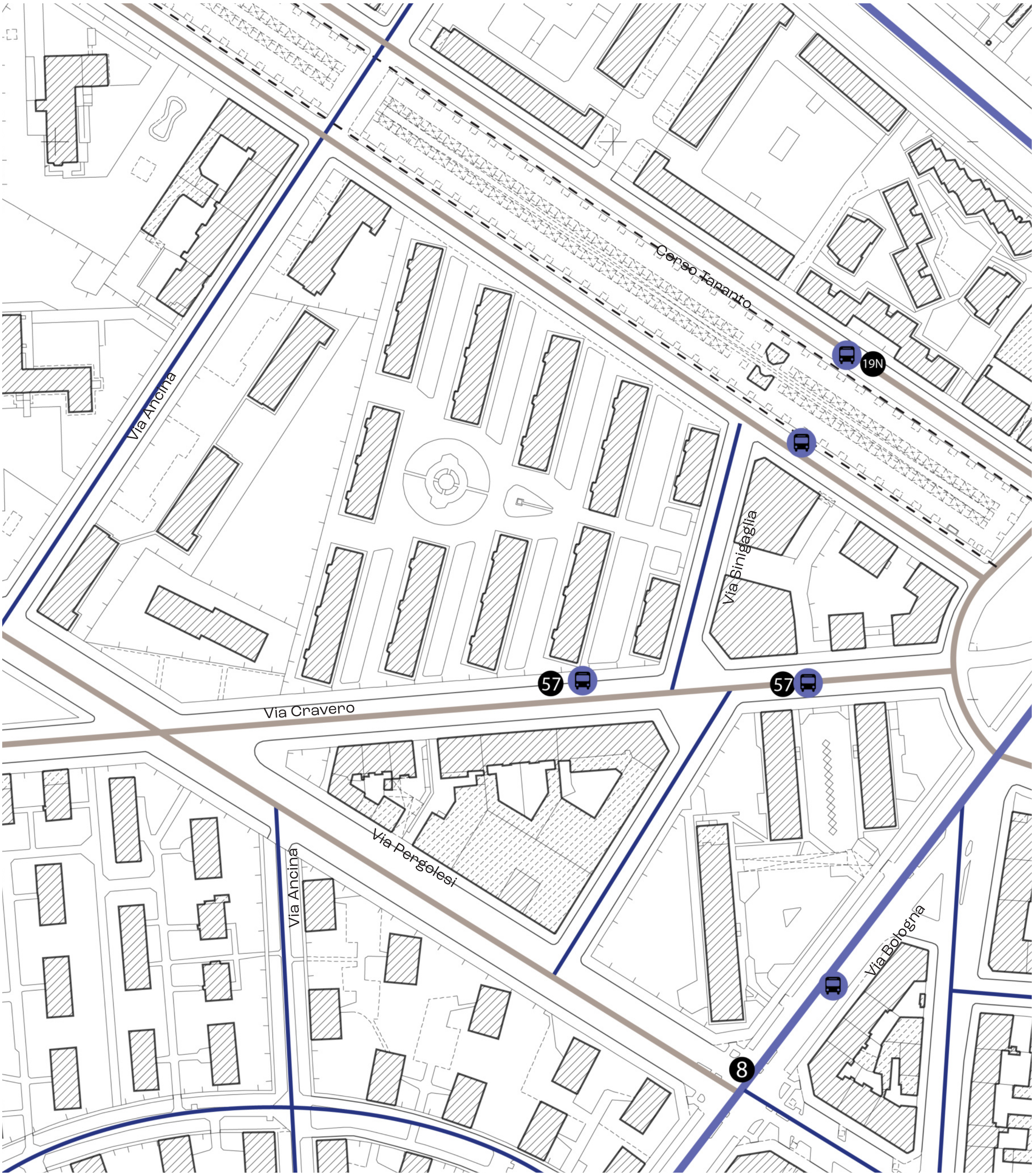


Figure 80: Mobility Map

Primary Network: Urban road

Secondary Network: Urban distribution road

Secondary Network: Neighbourhood Street

Cycling path

Bus stops

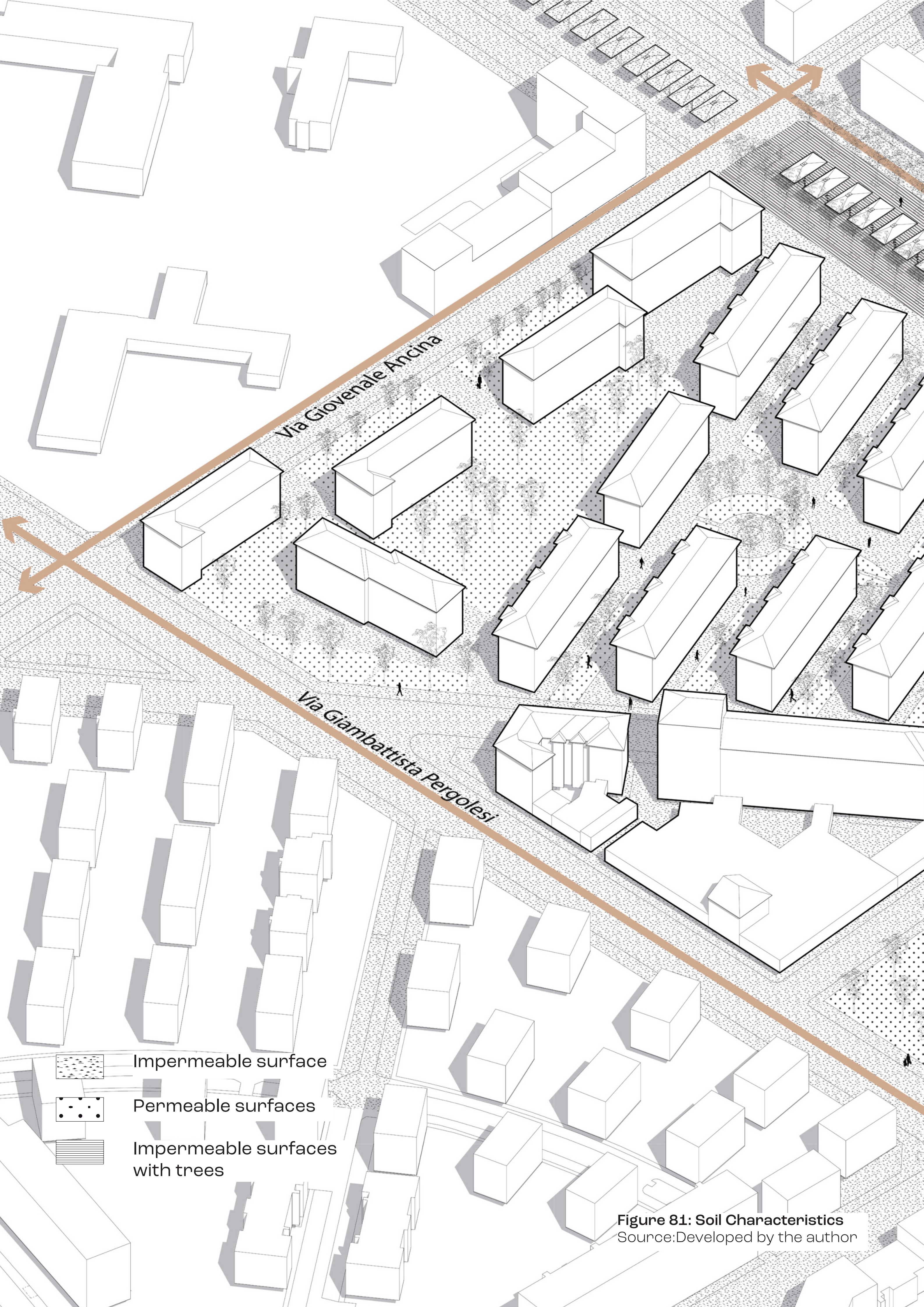
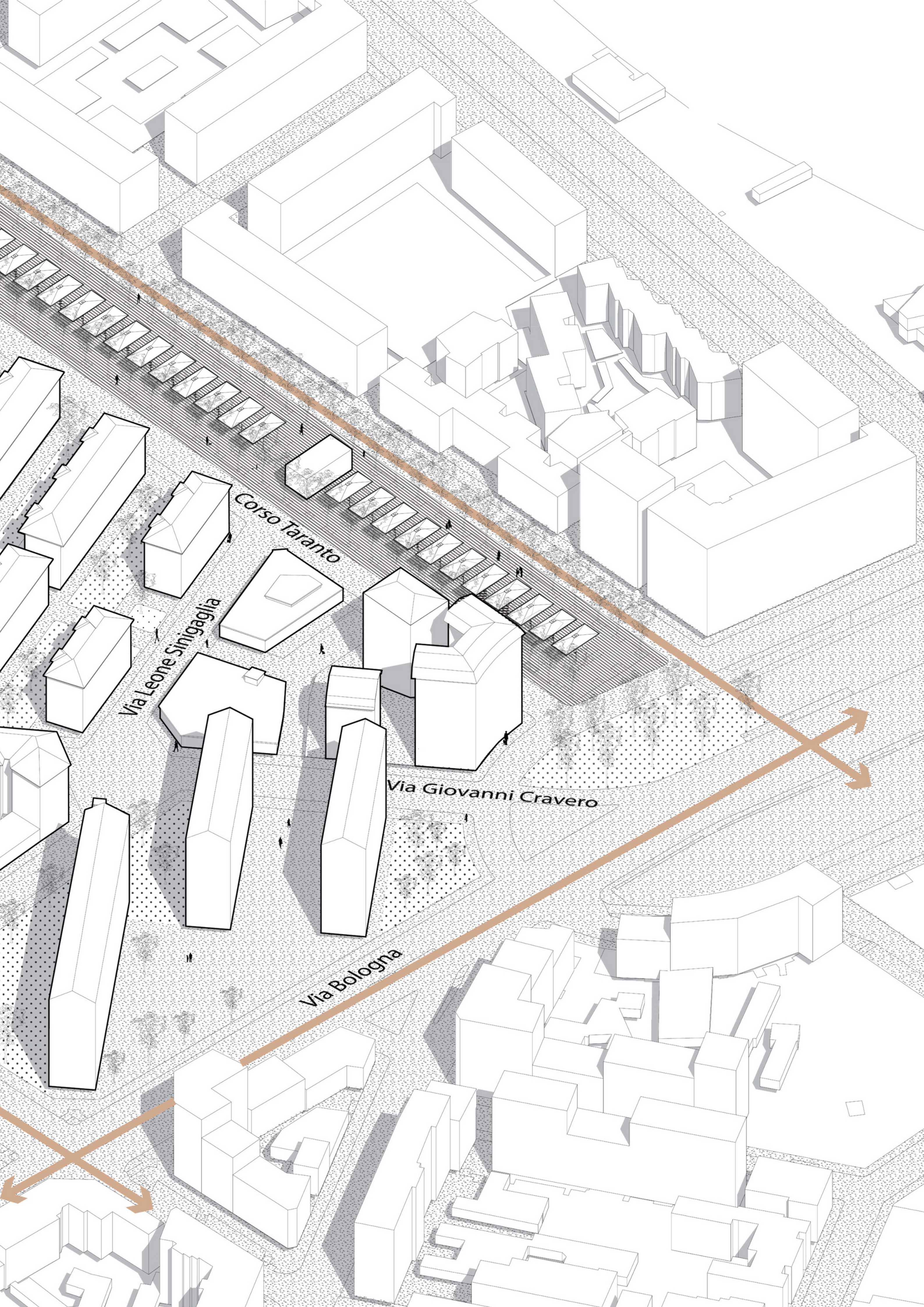


Figure 81: Soil Characteristics
Source:Developed by the author


Corso Taranto
Via Leone Sinigaglia
Via Giovanni Cravero
Via Bologna

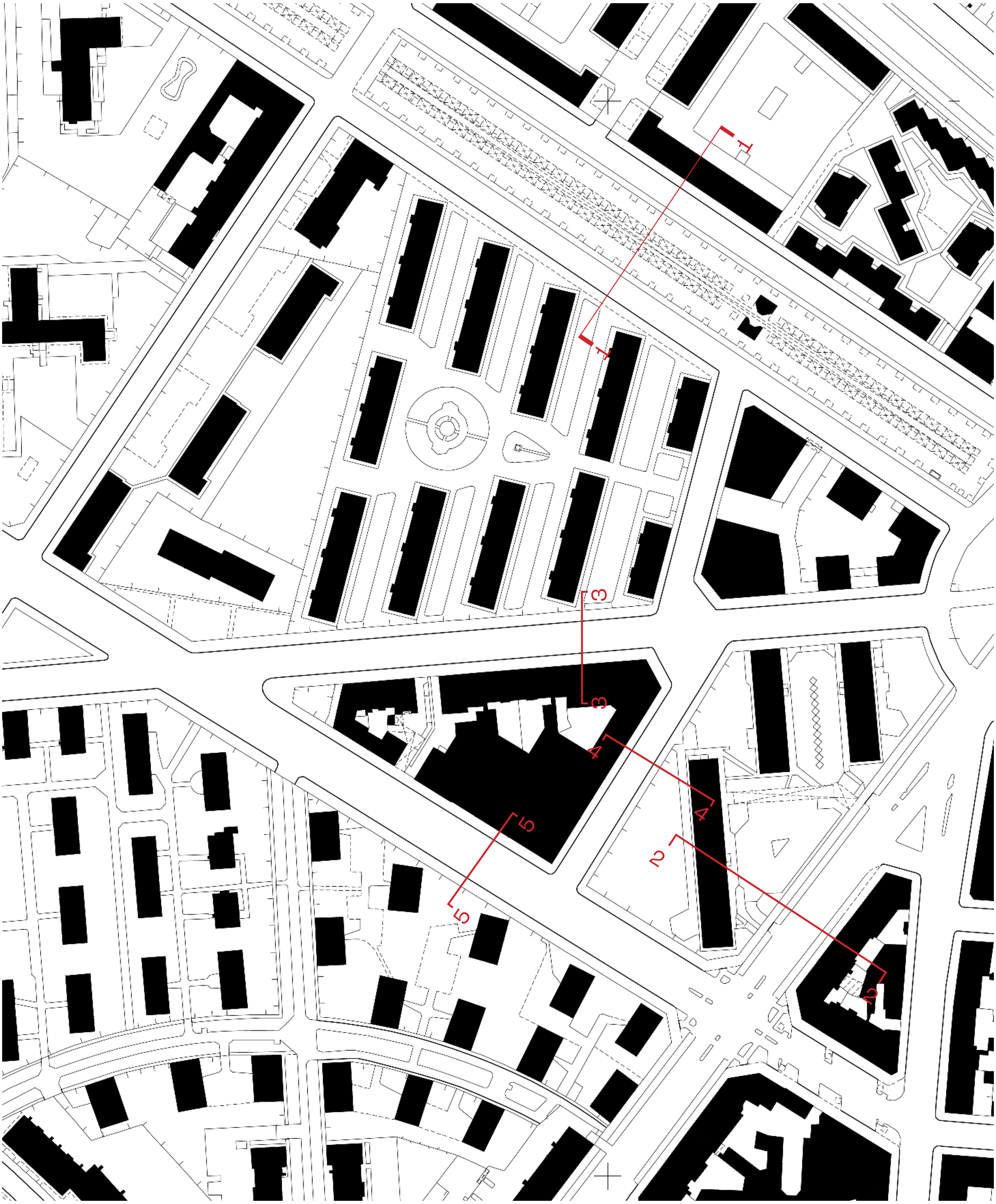


Figure 82: Site section
Source:Developed by the author

Road Sections

1. Corso Taranto
2. Via Bologna
3. Via Cravero A
4. Via Cravero B
5. Via Pergolesi

Corso Taranto section

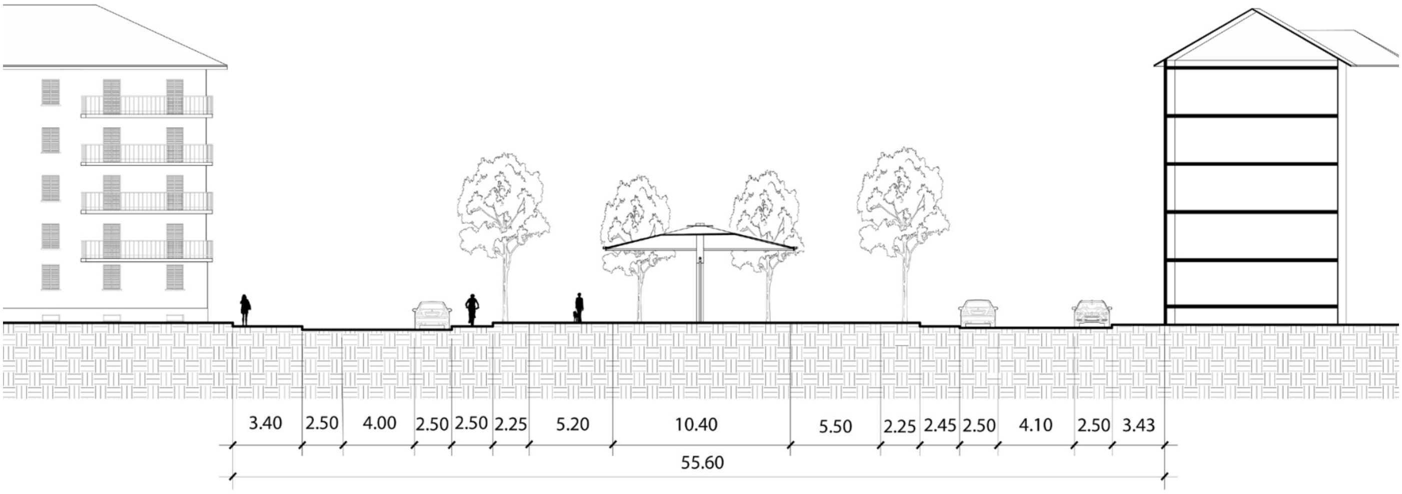


Figure 75: Corso Taranto section
Source:Developed by the author

Figure 82: Section reference
Source:Google Map

Via Bologna

Figure 83: Via Bologna section
Source:Developed by the author

Figure 85: Section reference
Source:Google Map

Via Cravero A

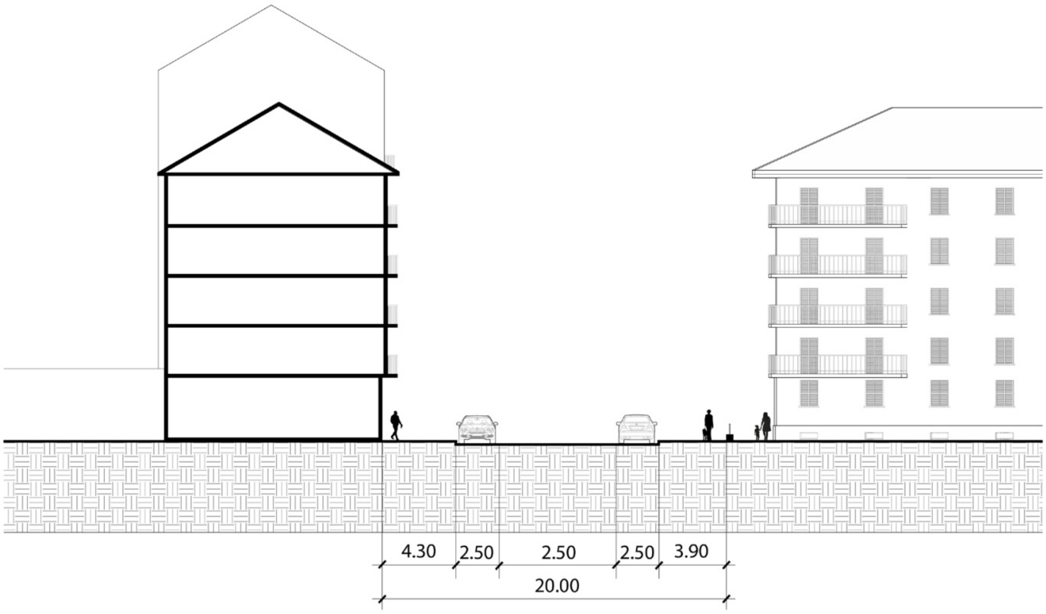


Figure 84: Via Cravero section
Source:Developed by the author

Figure 86: Section reference
Source:Google Map

Via Cravero B

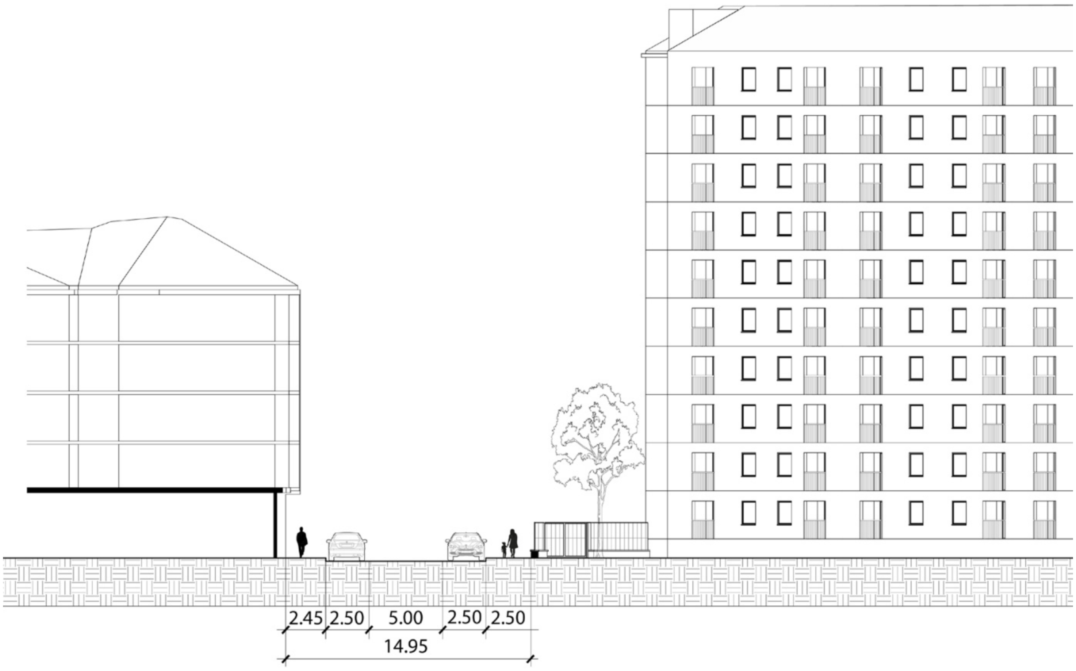


Figure 86: Via Cravero section B
Source:Developed by the author

Figure 87: Section reference
Source:Google Map

Via Pergolesi

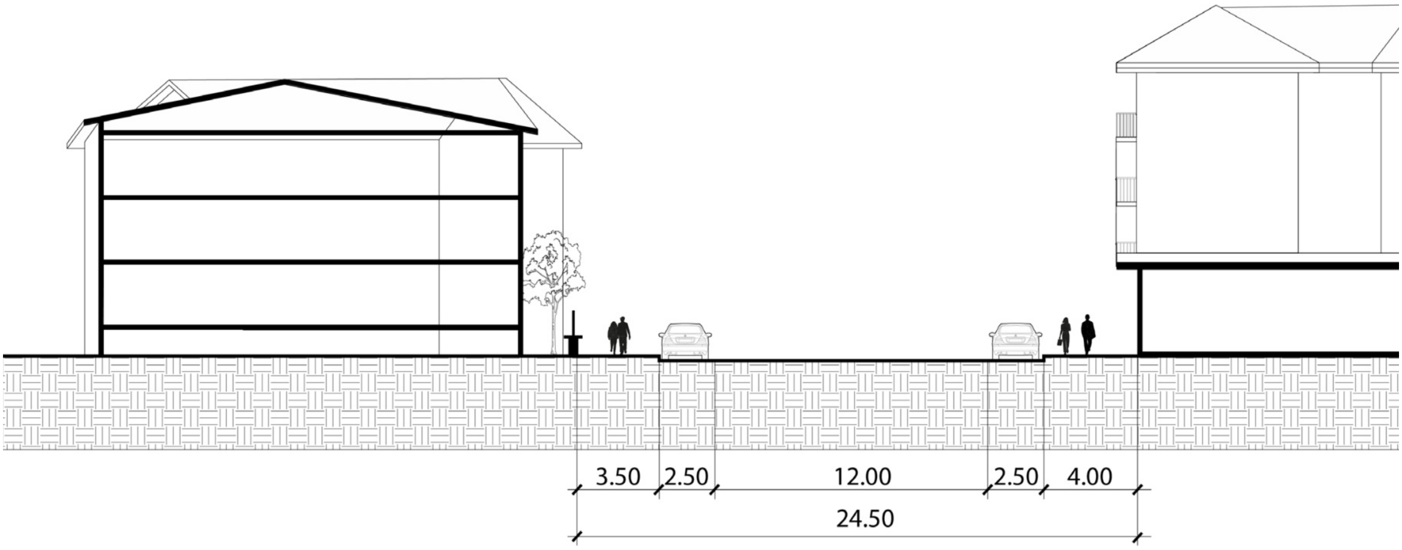


Figure 88: Via Pergolesi section
Source:Developed by the author

Figure 89: Section reference
Source:Google Map

MICROCLIMATE ASSESEMENT

Microclimate assesment

ENVI-met Overview

This thesis initiates a microclimate study using ENVI-met to analyze potential surface temperature, air temperature, wind speed, and Psychological Equivalent Temperature. Subsequently, solar analysis within Revit is employed to determine the sun's position during the summer, identifying facades requiring shading. As mentioned in the fourth chapter, ENVI-met is a widely utilized software for microclimate assessment, serving as scientific support for designing and evaluating urban microclimates. It aids in mitigating these climates through adaptation strategies, assessing outdoor thermal comfort in dynamic environments. As a Computational Fluid Dynamics (CFD) software, ENVI-met acts as a virtual "Wind Tunnel," simulating fluid dynamics, specifically air. The software proves valuable both before and after the design phase. Pre-design, it evaluates the existing microclimate conditions in the project site, addressing critical environmental aspects. Post-design, it assesses the project's potential impact on the urban environment. ENVI-met simulates the Urban Heat Island (UHI) and assesses Outdoor Air Quality (OAQ) by examining interactions between vertical and horizontal surfaces, air, and vegetation. With a grid-based structure, ENVI-met boasts high temporal and spatial resolution, typically ranging from 1-10m horizontally and simulation periods of 1-5 days (greatly influenced by the complexity of the model). Model area sizes are commonly within the range of 50x50 to 500x500 grid cells horizontally and 20-50 cells vertically.

ENVI_MET (Release 5.6.1) is composed by 4 interconnected modules
- Edit for modeling phase which includes the applications «Monde» and « Spaces »);
- Simulate (« Envi Guide» and « Envi Core»);
- Process for the evaluation of the thermal comfort indexes, based on the outdoor thermal conditions (« BioMet »);
- Visualize for the visualization and exportation of the results («Leonardo»

All modules are accessible through ENVI_MET Headquarte

Figure 90: ENVI-met Headquarter and simulation steps
Source:ENVI-met software

Input Data

The microclimate simulation conducted for the thesis involved a meticulous process of gathering and defining input data crucial for accurate modeling within the ENVI-met software. The project site, extracted from the carta tecnica of geoportale del comune di Torino, served as the foundational plan for developing the simulation in the spaces module. The area was systematically divided into a grid system of 160x160m in the horizontal direction and 50 grids in the vertical direction, with additional nesting grids at the boundaries to eliminate potential edge errors. A resolution of 5x5x1 was chosen for this simulation. Essential geometric data, including building heights and the layout of surface materials such as grass-covered surfaces, sidewalks, and roads, were collected from the Geoportale del comune di Torino and Google Maps. The input data related to public trees, dominated by Platanus occidentalis and Juglanis Nigra, were obtained from the geoportale del comune di Torino, modeled in the Albero module, and inserted into the spaces module.

Data Sources and Modification for Tree Modeling

Data for public trees were derived from the geoportale, but due to limited information on species, default options in ENVI-met were modified based on observed features from Google Maps. Buildings' heights and characteristics, as well as surface materials, were also collected from Geoportale and Google Maps. The simulation file was then set up in the ENVI-met guide module, with meteorological data obtained from the ARPA meteorological station on Via Foggia, 5, 10152 Torino. This station was chosen for its proximity to the research site and the

Material defined in Database Manager	Albedo	Emissivity	Material applied in Spaces module
Asphalt Road Dark	0.12	0.90	Vehicle access
Asphalt Road with red coating	0.4	0.90	Sidewalks
Concrete pavement Light	0.5	0.90	Courtyards internal walkways
Loamy Soil	0.0	0.90	Building and green areas base layer
Grass 12cm dense	0.2	0.97	Grass covered surfaces

Table 02: Site materials data

availability of all required meteorological parameters. The simulation aimed to analyze microclimatic conditions on the hottest day of the year, monitoring for 48 hours starting from July 19, 2023, at 00:00 am. Simulated meteorological parameters, including air temperature, wind direction, wind speed, relative humidity, and global solar radiation, were obtained for each hour.

Simulation Execution and Results

The simulation file underwent an automatic checking process within the ENVI-met core module to identify and rectify potential errors. Subsequently, the simulation was executed, and the computing time required was approximately 72 hours. This comprehensive microclimate

The simulation file underwent an automatic checking process within the ENVI-met core module to identify and rectify potential errors. Subsequently, the simulation was executed, and the computing time required was approximately 72 hours.

Hour	T Air °C	R.H. %	Wind Velocity (m/a)	Wind Direction (°)
00.00 am	28.4	44	1.0	86
01.00 am	27.8	47	0.9	80
02.00 am	27.4	50	1.0	22
03.00 am	27.2	50	1.0	44
04.00 am	26.5	52	0.9	25
05.00 am	26.4	53	0.8	14
06.00 am	27.1	50	1.2	353
07.00 am	27.9	47	2.2	42
08.00 am	29.5	42	2.1	44
09.00 am	30.9	39	2.2	36
10.00 am	32.2	34	2.4	26
11.00 am	33.2	32	2.2	22
12.00 pm	34.5	29	0.5	230
13.00 pm	34.8	28	2.2	31
14.00 pm	35.4	29	3.2	66
15.00 pm	35.4	30	3.1	56
16.00 pm	34.8	30	3.1	60
17.00 pm	34.9	29	2.6	46
18.00 pm	34.0	29	3.2	47
19.00 pm	31.5	41	2.4	6
20.00 pm	30.5	45	1.8	36
21.00 pm	29.3	51	1.8	62
22.00 pm	28.1	57	1.8	86
23.00 pm	28.4	54	0.7	161

Table 03: Input Meteorological Data of 19-07-2023
Source: https://www.arpa.piemonte.it/dati-ambientali/richiesta-dati-orari-meteorologici

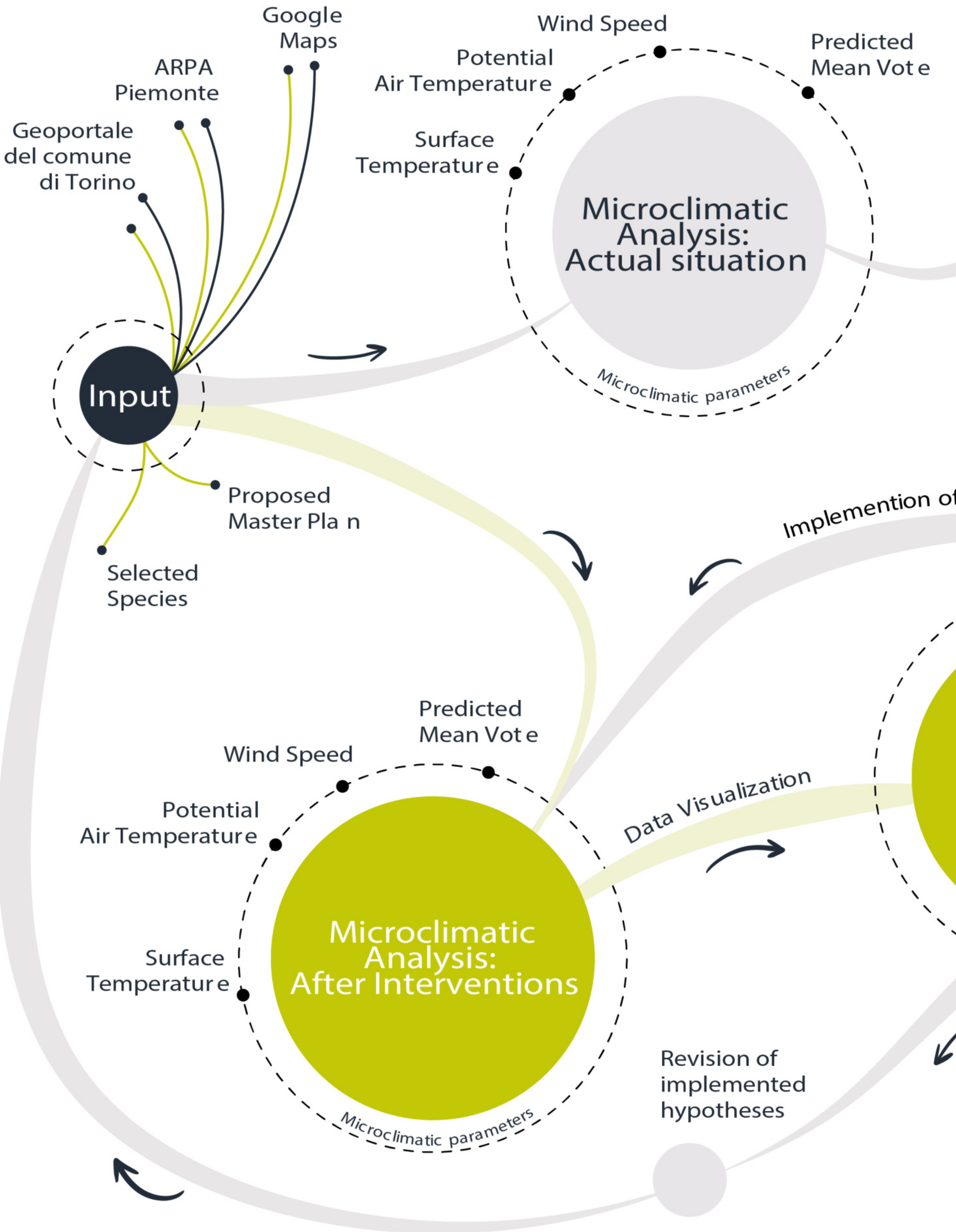
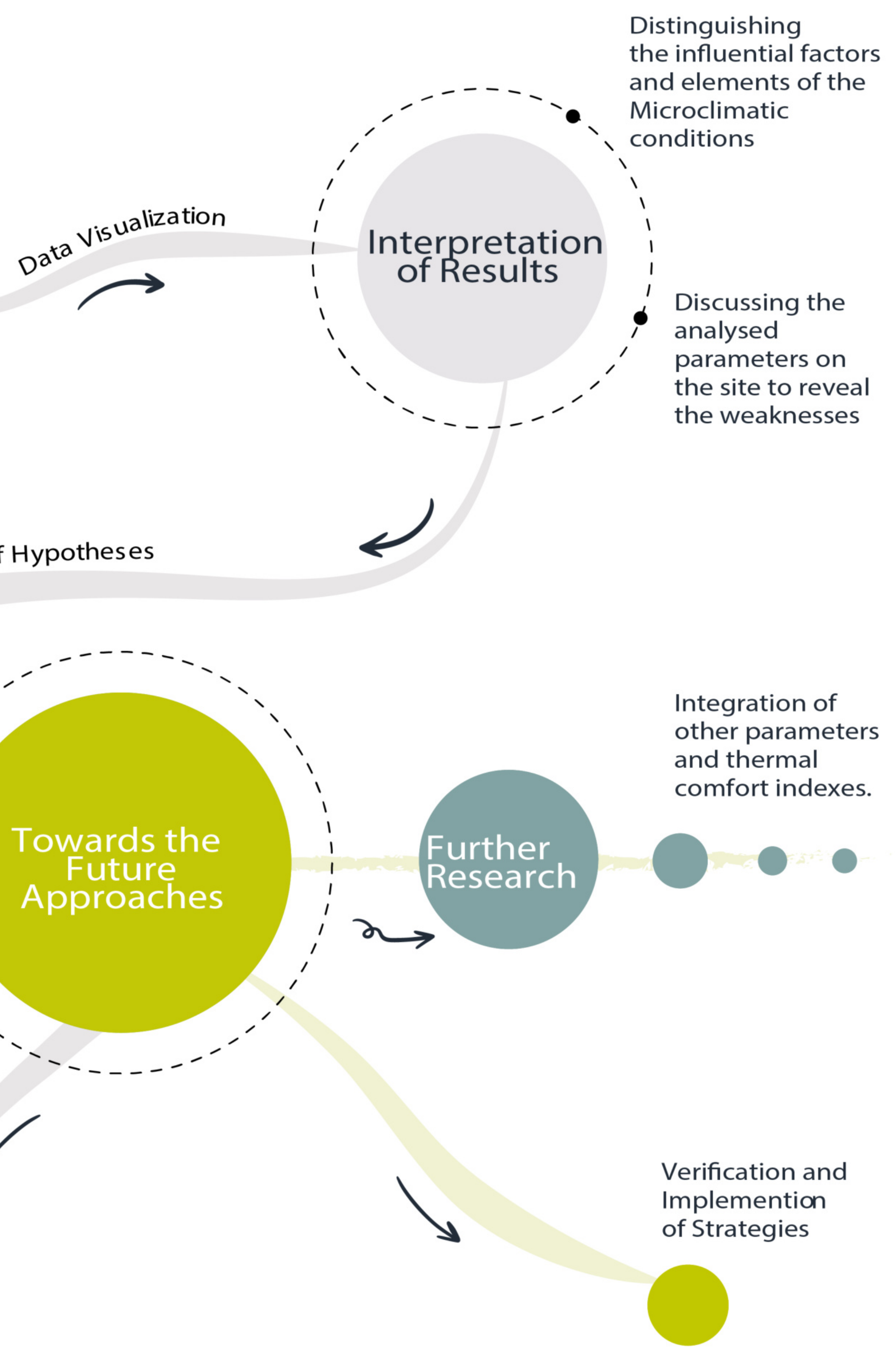


Figure 90: Methodology of microclimatic assessment using the Envi-Met software.
Source: Khachatourian Saradehi, L., & Khachatourian Saradehi, A. 2022. Nature-Based Solutions For Urban Adaptivity: Regenerating Former OSI-GHIA Industrial Site. Doctoral dissertation, Politecnico di Torino.



LEGEND

Input data - Existing situation

Input data - Implementation of hypotheses

Results interpretation

The simulation results encompass an analysis of potential air temperature, surface temperature, wind velocity, and PMV thermal comfort index. Representative hours for the day, specifically 10:00 am, 12:00 pm, 14:00 pm, and 16:00 pm on July 19, 2022, were chosen to include critical hot periods. Except for surface temperature, data for all other outputs are obtained from a height of 2.5 meters above ground level. The selection of this height is based on the converting principle of K value to meters and its proximity to the average human height, making it a suitable reference point. The calculation of the PMV thermal comfort index is carried out in the Bio-met module using simulation atmosphere data, considering various K levels. As previously mentioned in this study, the Leonardo module of ENVI-met serves as the platform for visualizing the simulations. In ENVI-met, each simulation comprises a broad array of data, which can be extracted in Leonardo based on the study's focus. For this research, key data extracted into Leonardo include atmospheric and surface parameters from the simulation, specifying details such as wind speed, etc., for presentation at specific K levels.

Surface Temperature Analysis:
The results reveal a stark contrast in surface temperatures across different spaces within the neighborhood. Major asphalt roads, including Via Giovanni Cravero and Via Bologna, exhibited significantly elevated surface temperatures, exceeding 38.87°C at 10:00 am and soaring to over 47.77°C by 4:00 pm. This phenomenon is primarily attributed to the prevalent use of asphalt paving materials, which are notorious for their heat-absorbing properties. Notably, Corso Taranto, characterized by the presence of numerous trees, recorded lower surface temperatures, emphasizing the cooling effect of green infrastructure.

Potential Air Temperature Analysis:
The potential air temperature dynamics underscore the influence of various urban elements on thermal conditions. Corso Taranto and building courtyards consistently exhibited lower potential air temperatures, indicating the moderating impact of green spaces. Conversely, areas along major streets experienced higher air temperatures, reaching up to 29.64°C to 28.87°C at 12:00 pm and 14:00 pm, respectively. The juxtaposition of these findings emphasizes the role of green infrastructure in mitigating air temperature extremes, contributing to a more comfortable urban environment.

Wind Speed Analysis:
Wind speed patterns contribute significantly to the dispersion of heat and the overall comfort of urban spaces. Streets displayed relatively higher wind speeds, ranging from 0.45 m/s to >1.41 m/s, facilitating the dissipation of heat. Internal courtyards, however, exhibited lower wind speeds, particularly below building heights, indicating potential heat retention. This emphasizes the need for strategic planning to optimize wind flow for enhanced urban comfort.

Psychological Equivalent Temperature (PET) Analysis:
The PET values portray the perceived temperature, incorporating factors like humidity and wind speed. Streets, especially those without significant green cover, recorded PET values exceeding 50.59°C at 10:00 am and escalating to >54.96°C by 4:00 pm. Contrastingly, courtyards and shaded sidewalks, influenced by greenery and building shadows, maintained relatively lower PET values, ranging from <26.39°C to <30.82°C during the same period. This accentuates the significance of green infrastructure in fostering a thermally comfortable urban realm.

Influential Factors

Paving Material:
The choice of paving material emerged as a crucial factor influencing microclimate outcomes in the simulation. Asphalt-dominated surfaces, particularly major roads like Via Giovanni Cravero and Via Giambattista Pergolesi, exhibited elevated surface temperatures (>38.87 °C) during peak hours (10 AM, 12 PM, 2 PM, and 4 PM). The high heat retention capacity of asphalt exacerbates the Urban Heat Island (UHI) effect, contributing to discomfort and potentially adverse health effects (Santamouris, M. et al., 2015). Alternatives such as permeable pavements could mitigate this effect by allowing water infiltration and reducing surface temperatures (Yang, J., Wang, Z.-H., & Chen, B., 2017).

Vegetation and Shading:
The presence of vegetation, especially in Corso Taranto's Market area with numerous trees, played a pivotal role in mitigating the adverse impacts of UHI. Surface temperatures in these areas were consistently lower (<21.54 °C), showcasing the cooling effect of greenery. Trees provide shade, reduce solar absorption, and engage in evapotranspiration, collectively contributing to a moderated microclimate (Akbari, H., Pomerantz, M., & Taha, H., 2001). The importance of preserving or incorporating green spaces within urban planning strategies is underscored, aligning with findings in various urban studies (Kabisch, N., et al., 2017).

Building Layout:
Building layout significantly influenced wind patterns and, consequently, the microclimate within Regio Parco. Streets exhibited higher wind speeds (0.45 m/s to >1.41 m/s), fostering better ventilation. In contrast, internal courtyards experienced lower wind speeds (0.34 m/s to <0.04 m/s), indicative of potential stagnation. The arrangement and height of buildings impact airflow, influencing temperature distribution and contributing to localized heat islands (Oke, T. R., 1982). Optimizing building configurations to enhance natural ventilation is a critical consideration in urban design for microclimate regulation.

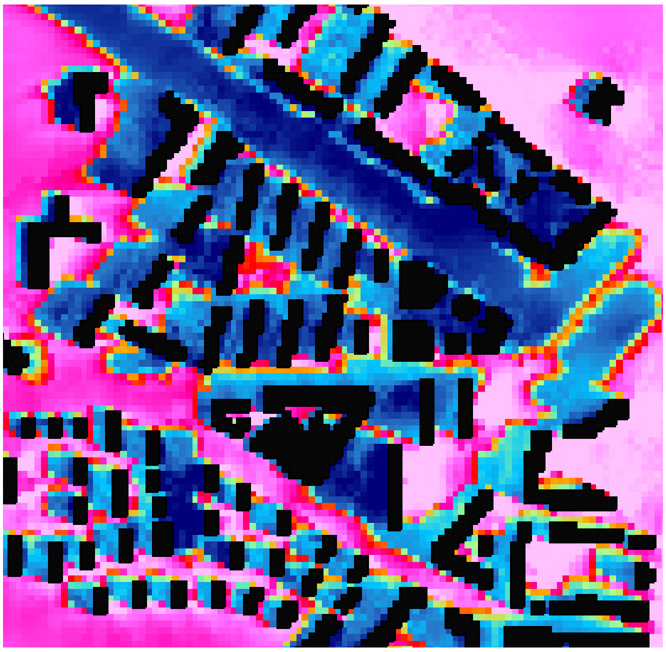
Urban Form:
The overall urban form of Regio Parco, characterized by a mix of residential blocks, major streets, and courtyards, manifested distinct microclimatic conditions. Courtyards, shielded from direct sunlight, demonstrated the potential for maintaining lower temperatures, emphasizing the importance of open spaces within the urban fabric. The varied built environment contributed to spatial heterogeneity in microclimate, reinforcing the idea that diverse urban forms influence local climates differently (Arnfield, A. J., 2003).

Time of the Day:
Regio Parco's microclimate experienced dynamic fluctuations throughout the day, with 10 AM, 12 PM, 2 PM, and 4 PM chosen as representative hours to capture nuanced diurnal variations. Afternoon hours consistently exhibited higher surface temperatures, aligning with established climatological patterns. This temporal variability emphasizes the importance for urban planners to adopt adaptive design strategies that account for diurnal changes in microclimate conditions (Oke, 1987).

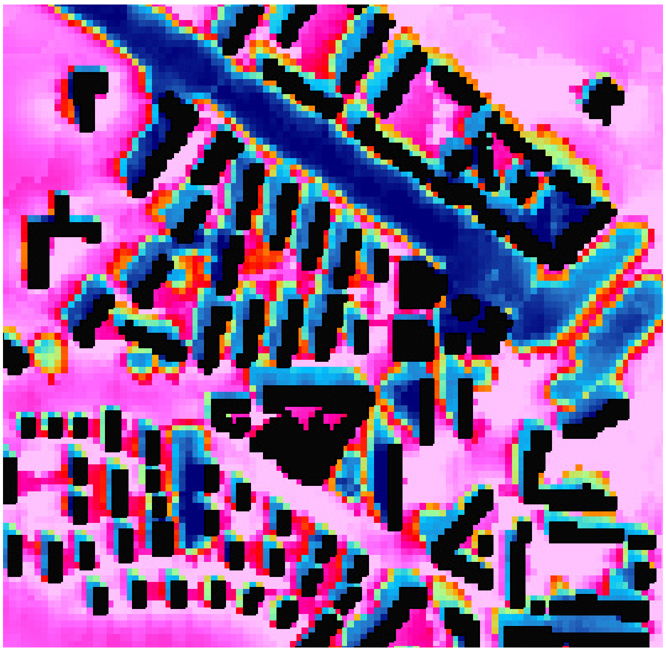
Conclusion
The microclimate in Regio Parco is a complex interplay of various urban factors. Paving materials, vegetation, building layout, and urban form collectively shape the local climate, influencing temperature, wind patterns, and overall environmental comfort. The temporal dimension adds further complexity, emphasizing the need for holistic and context-specific urban design strategies to mitigate the adverse effects of the Urban Heat Island and enhance the overall livability of the neighborhood.

Figure 91: Potential surface temperatures

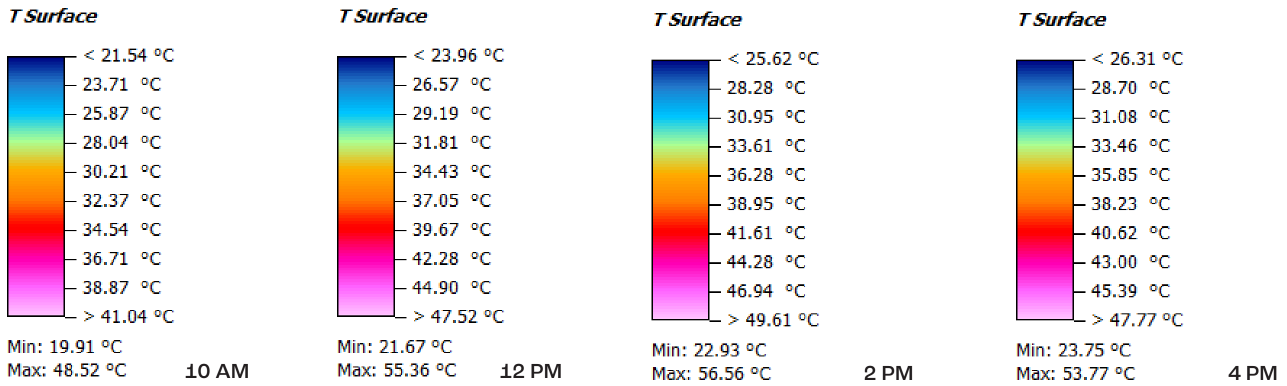
Existing condition

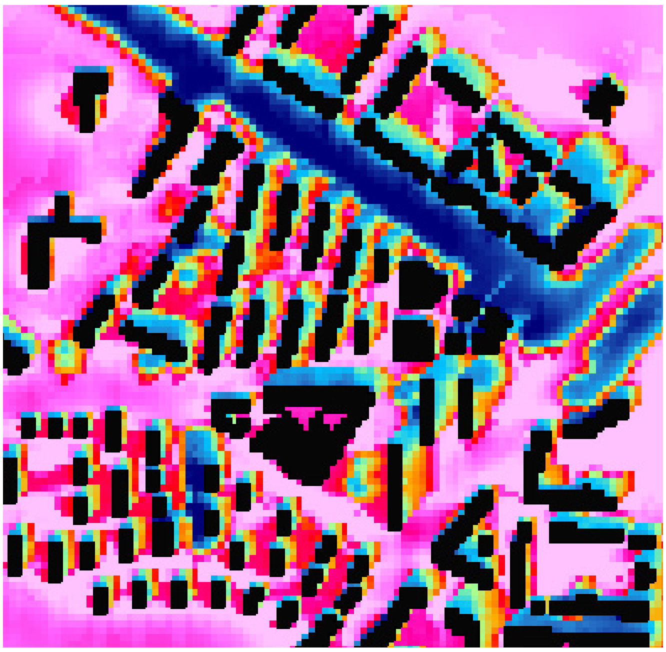


10 AM

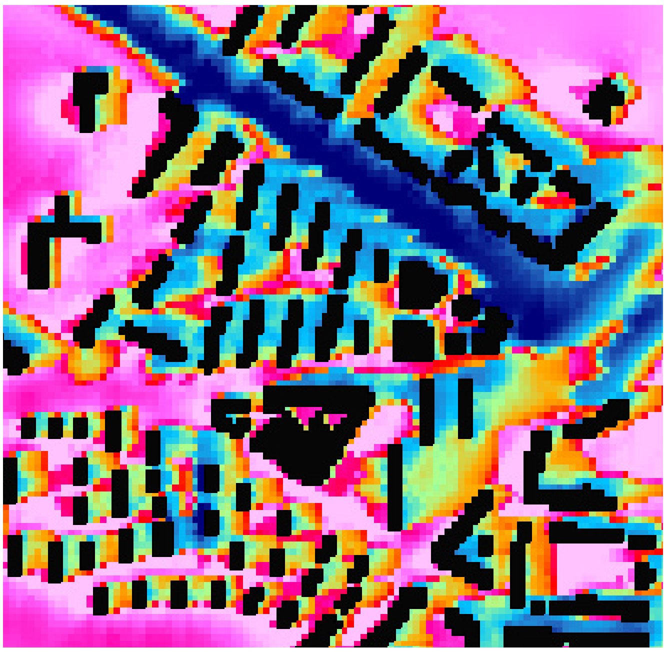


12 PM





2 PM



4 PM

Figure 92: Potential air temperatures

Existing condition

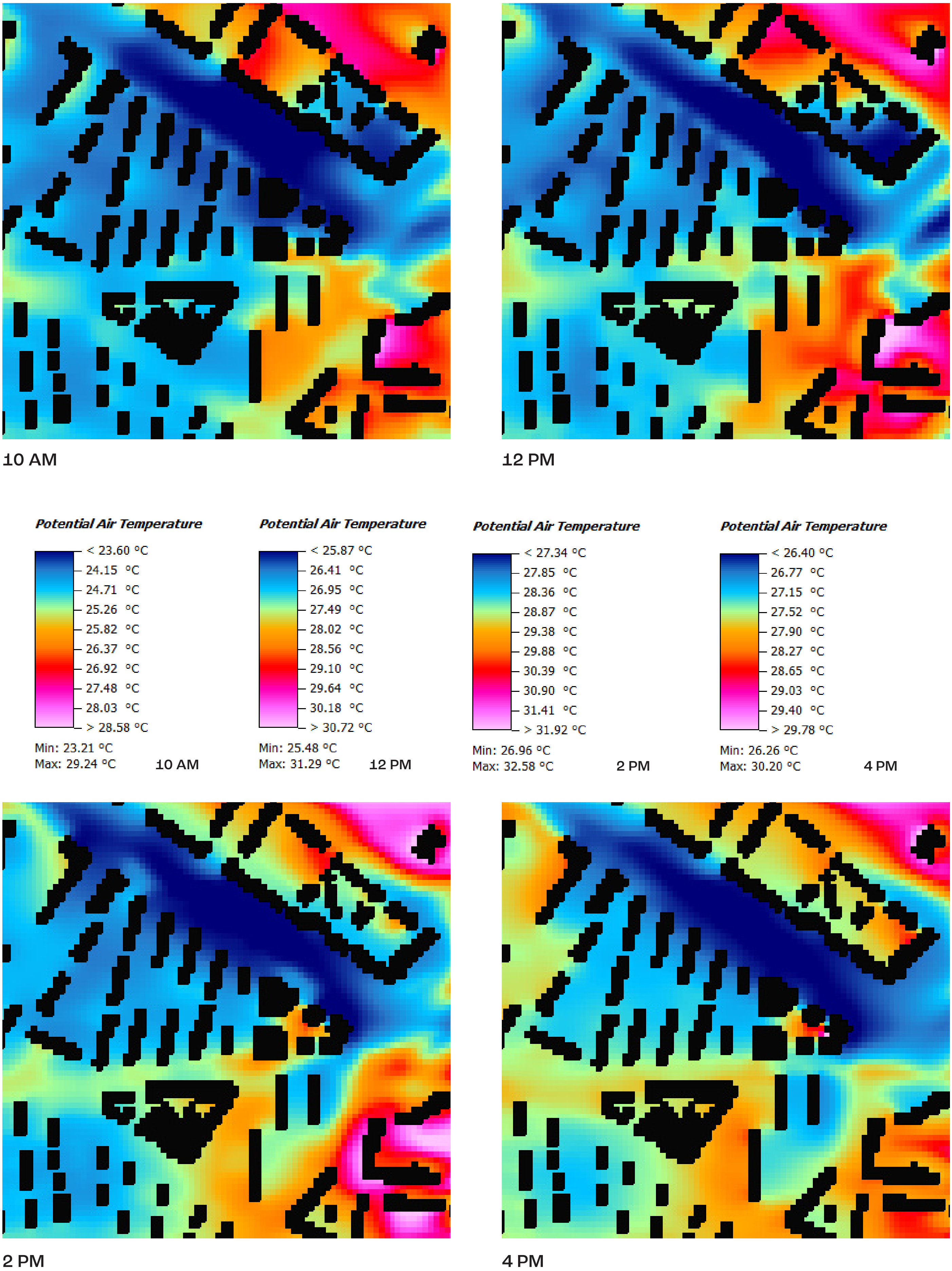
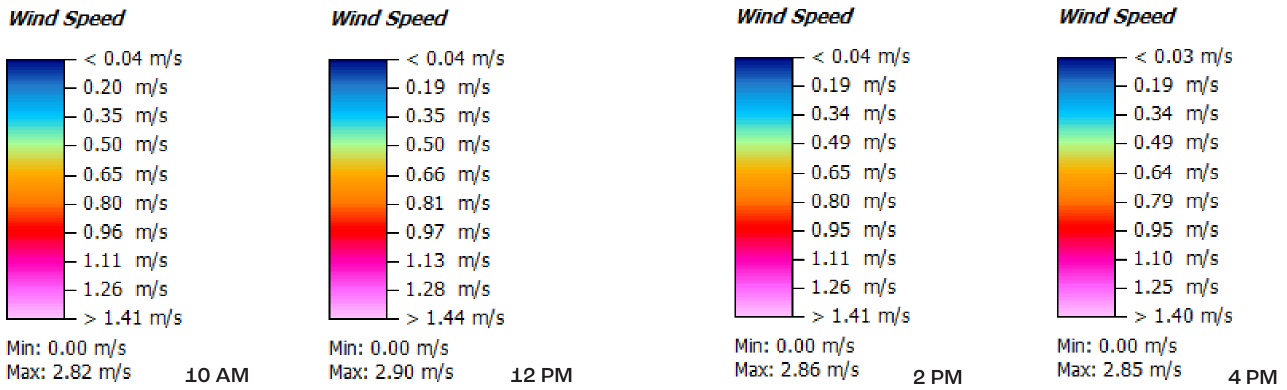


Figure 93: Wind speed

Existing condition

10 AM

12 PM



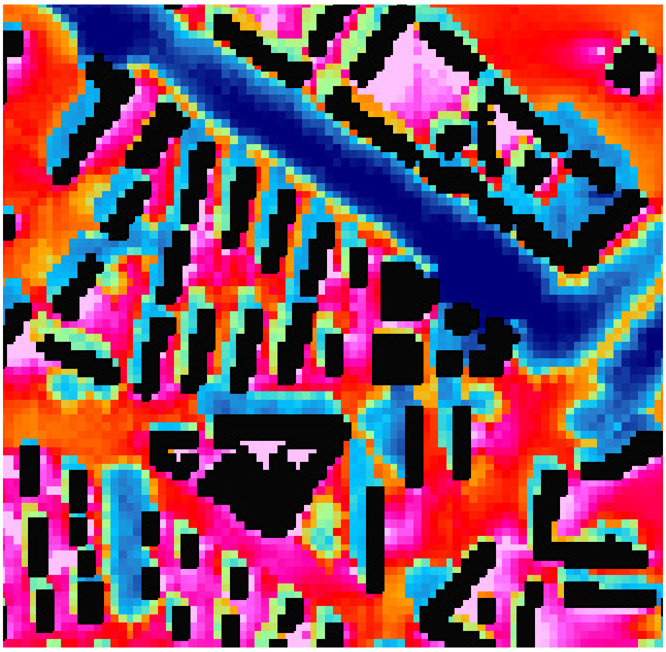
2 PM

4 PM

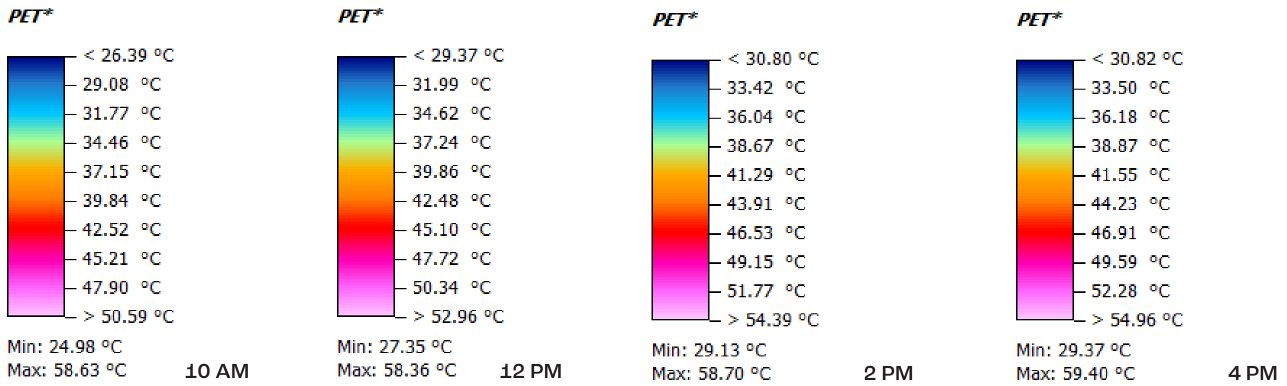
Figure 94: Psychological Equivalent Temperature

Existing condition

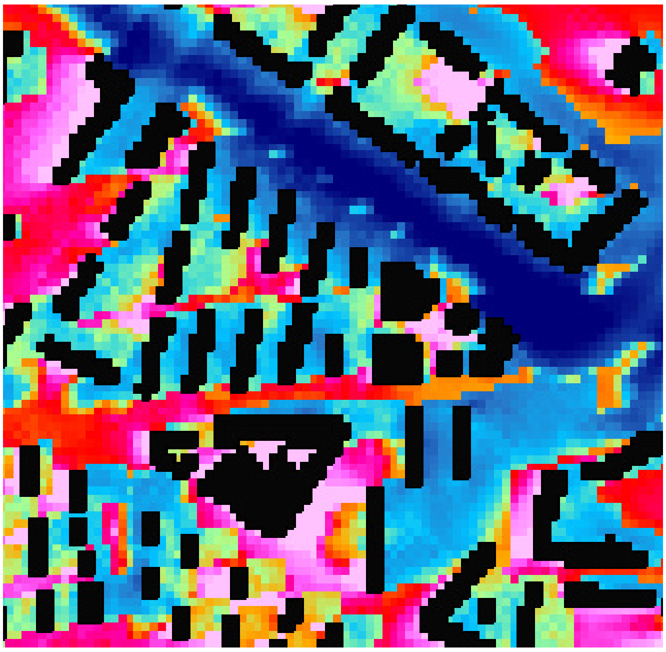
10 AM



12 PM



2 PM



4 PM

Solar study at 12:00pm

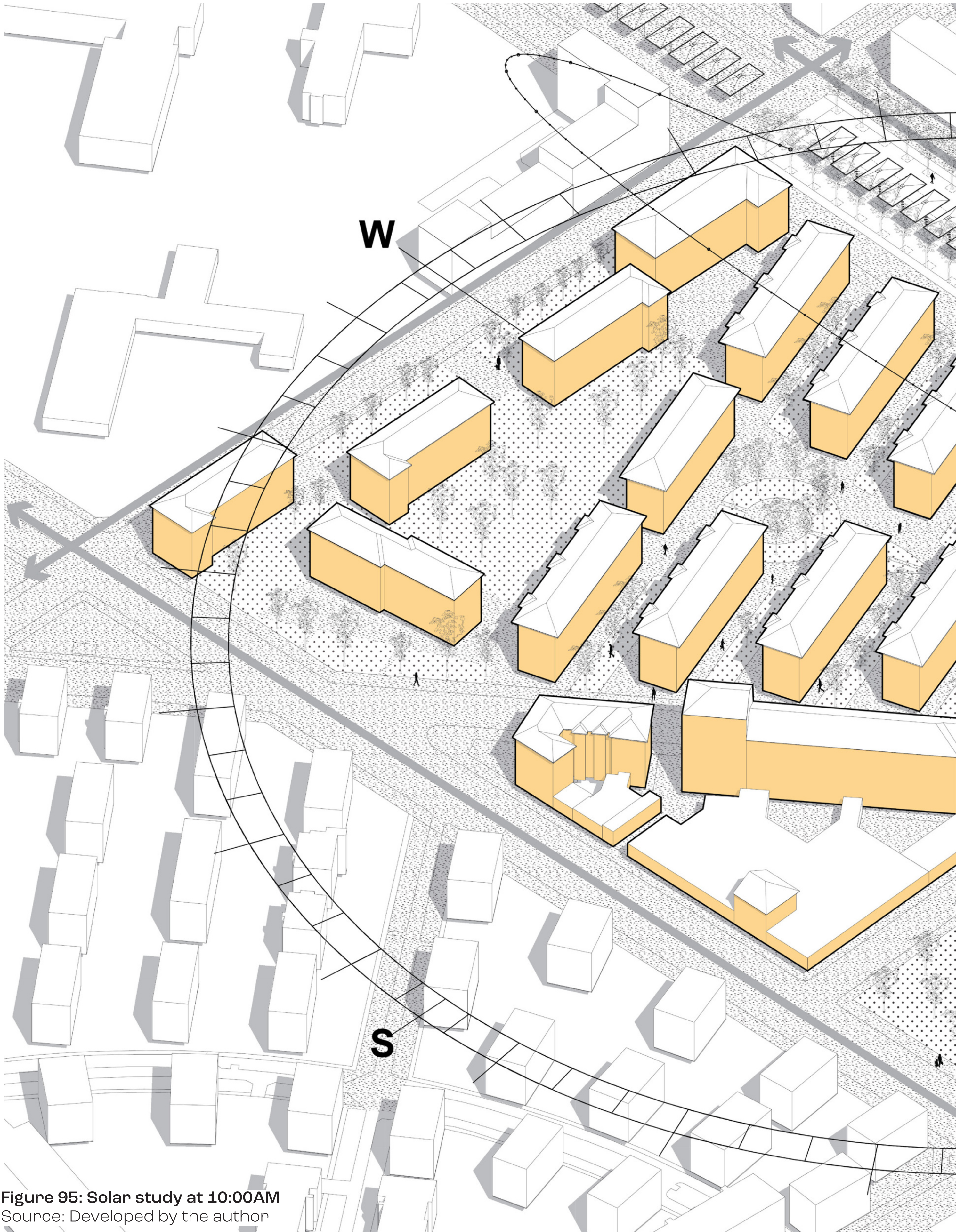
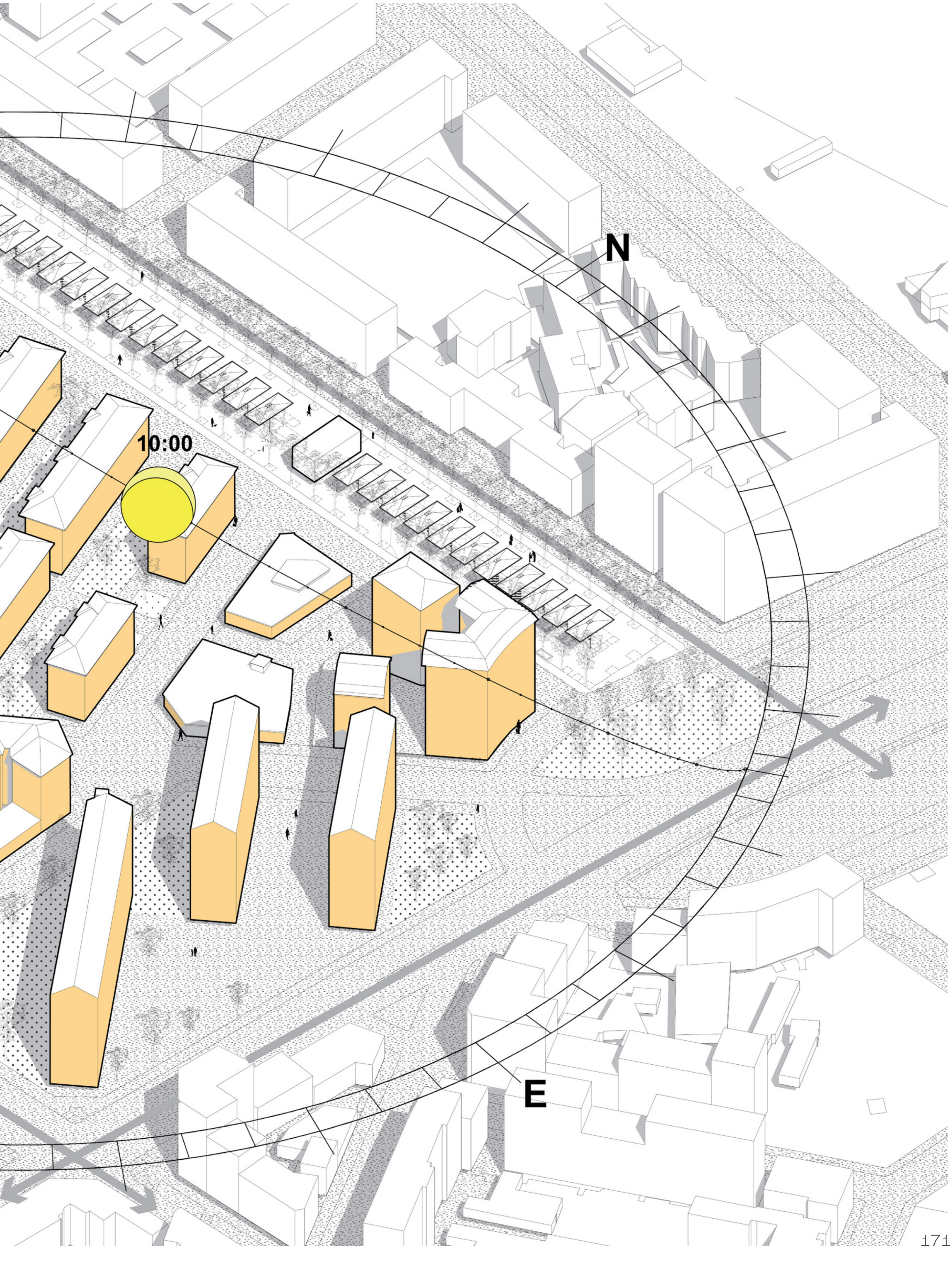


Figure 95: Solar study at 10:00AM
Source: Developed by the author


10:00
N
E

Solar study at 12:00pm

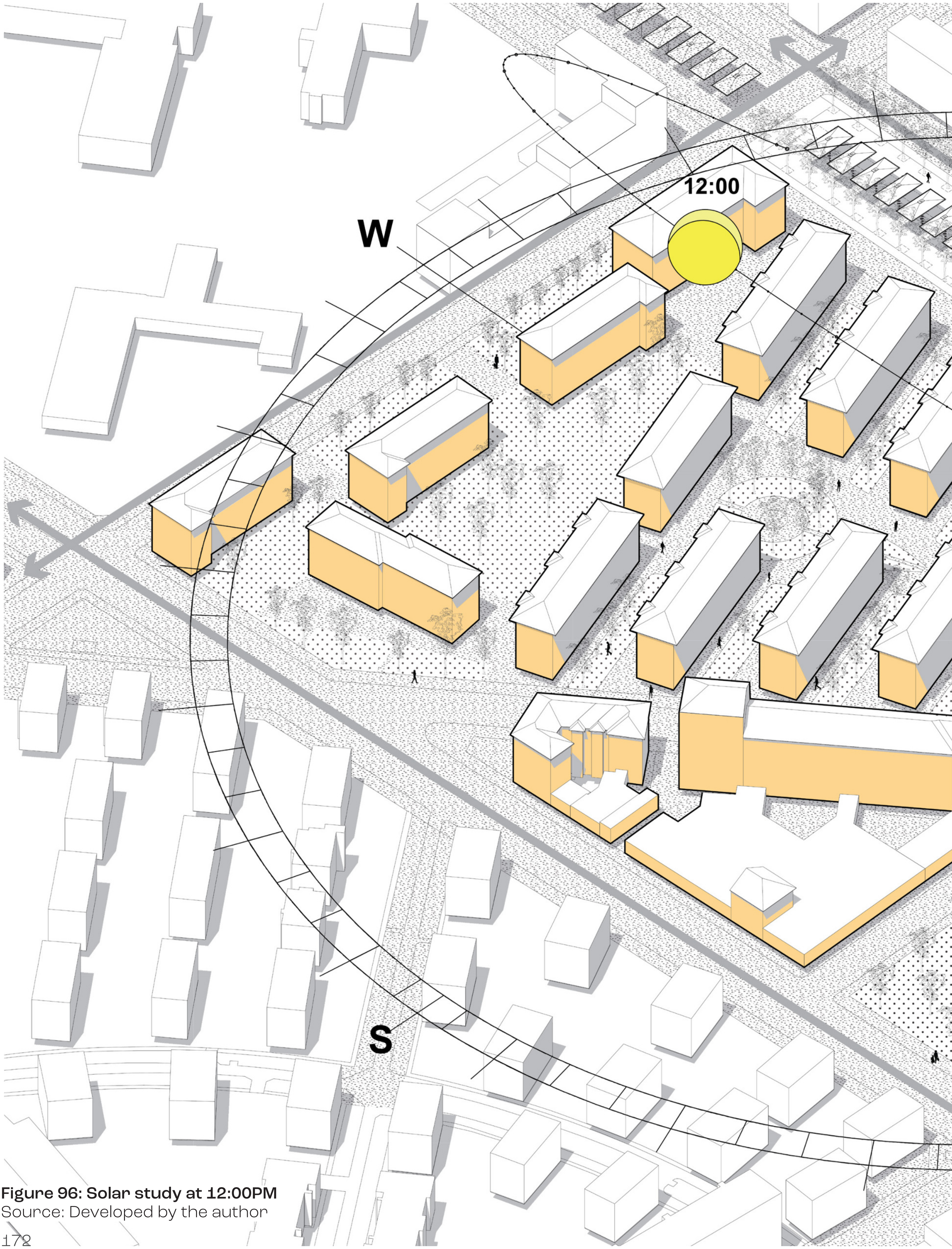
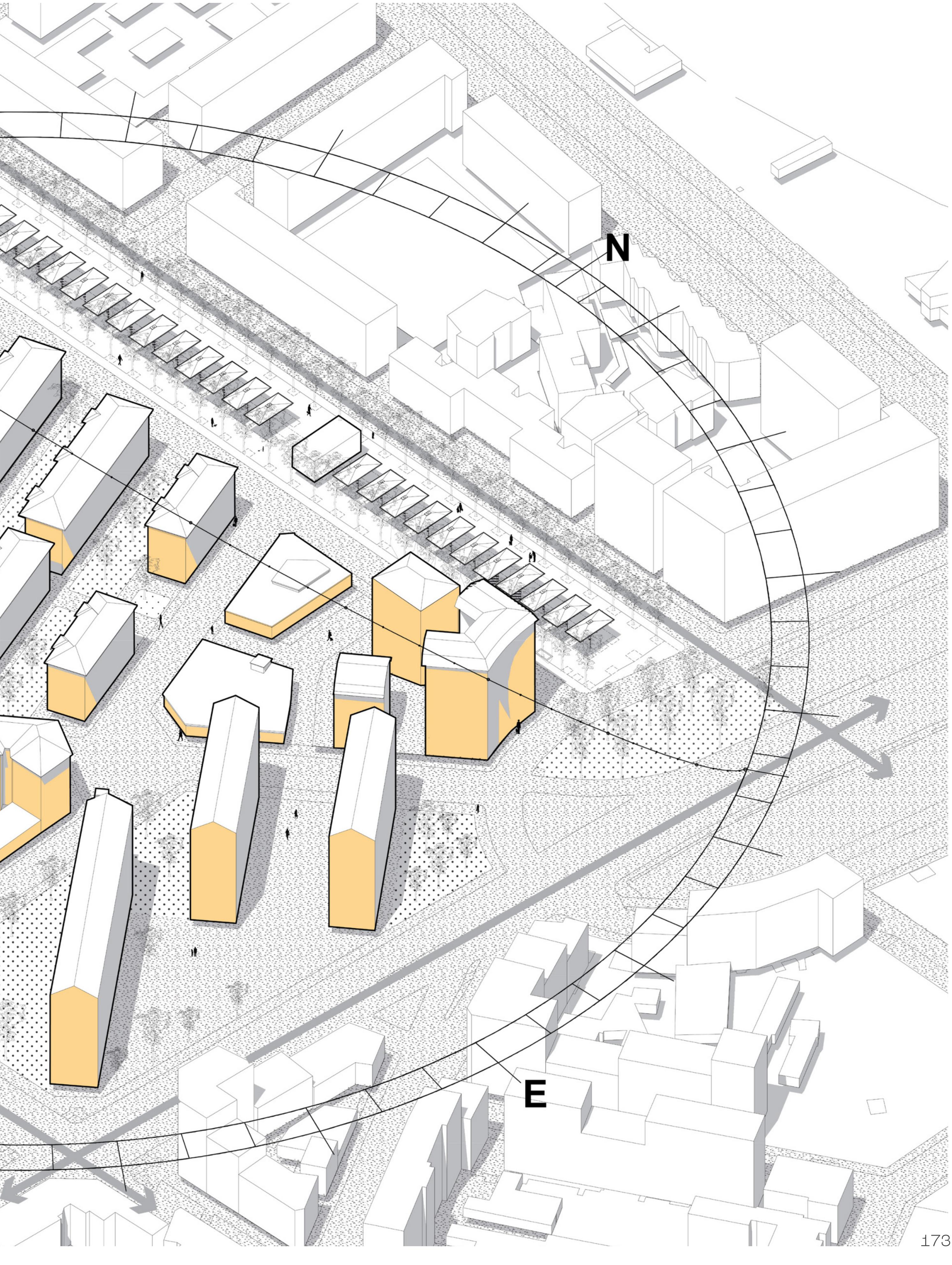


Figure 96: Solar study at 12:00PM
Source: Developed by the author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Solar study at 14:00pm

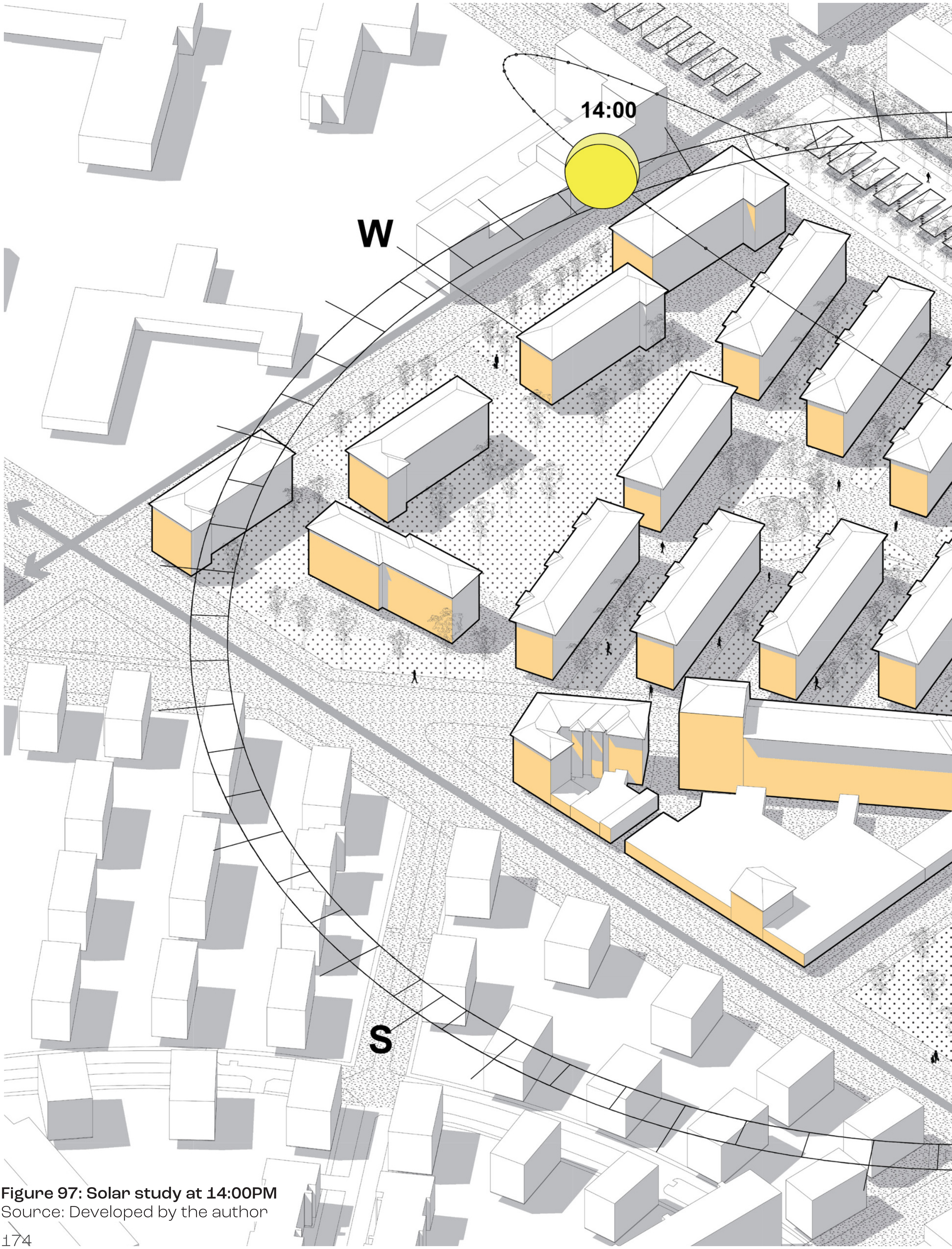
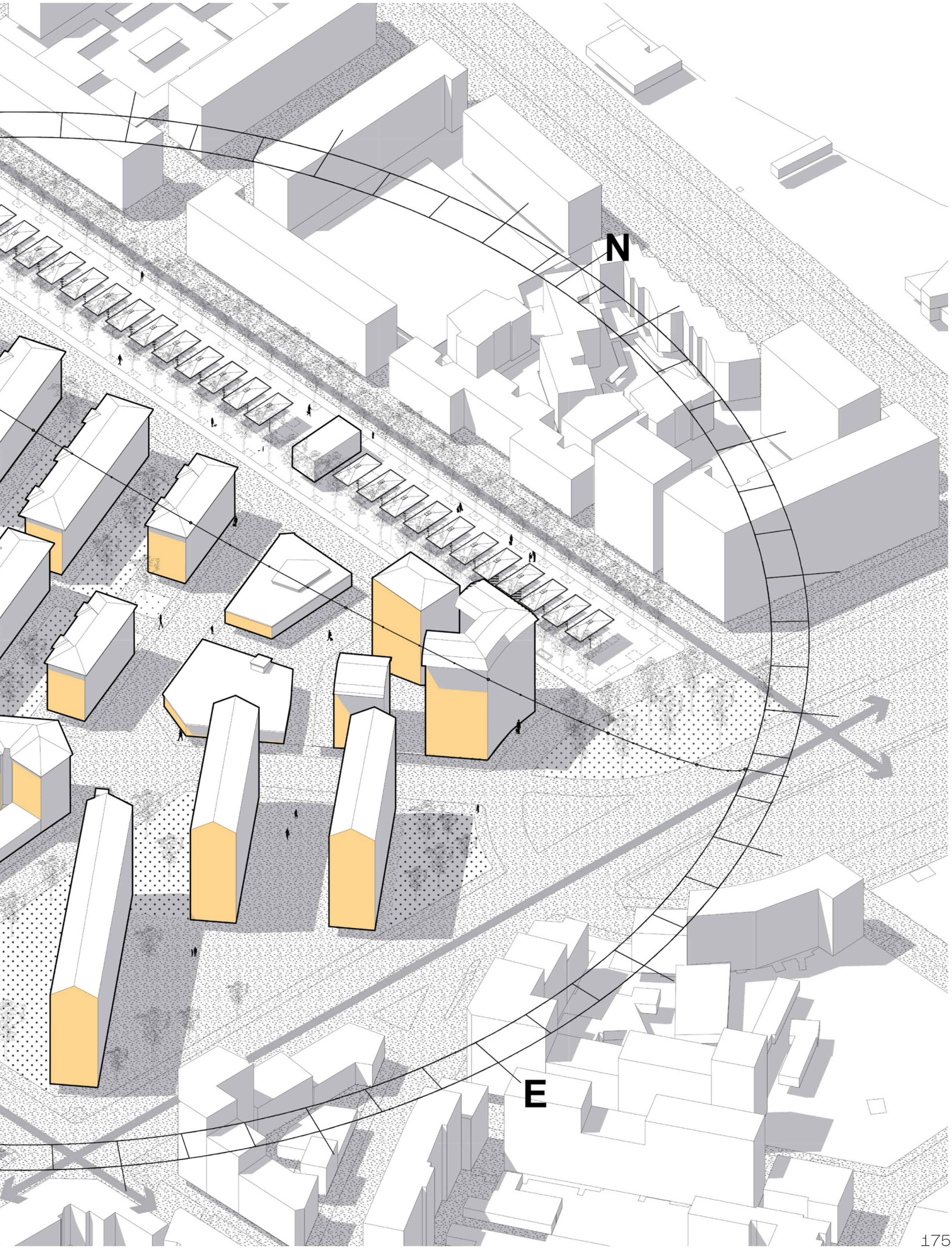


Figure 97: Solar study at 14:00PM
Source: Developed by the author


N
E

Solar Analysis outcome and Design Interventions

Solar studies are integral to the design process, particularly in the realm of architectural design, where the impact of sunlight on the built environment is a critical consideration. This discussion centers on the solar analysis conducted, with a focus on the identified issues during specific times of the day and the subsequent design interventions implemented to mitigate these challenges.

Findings:

The axonometric drawings generated from Revit software provided valuable insights into the solar exposure of the building facades throughout the day. At 10 AM, 12PM, the South-eastern and North-eastern facades were revealed to be inundated with direct sunlight, rendering the balconies uninhabitable during this period. By noon, the solar exposure shifted to the South-eastern and South-western facades, posing a significant challenge, while at 2 PM, the entire South-western facades became uninhabitable due to the absence of integrated shading systems.

Design Interventions:

To address these challenges, a comprehensive redesign of the building facades was undertaken, primarily focusing on eleven social housing blocks. The alterations involved a transition from traditional brick finishes to terracotta claddings, coupled with the integration of slidiable vertical shading systems. Additionally, all flat-roofed blocks with black roofs were transformed into green roofs.

Rationale for Material Change:

The shift from bricks to terracotta claddings serves a dual purpose. Firstly, terracotta possesses inherent thermal properties that aid in temperature regulation, reducing heat absorption compared to traditional bricks. Secondly, the aesthetic appeal of terracotta aligns with contemporary architectural trends, contributing to an enhanced visual identity for the social housing complex.

Vertical Shading Systems:

The integration of slidiable vertical shading systems addresses the critical issue of solar exposure on balconies and building facades. These shading systems are strategically positioned to mitigate the impact of direct sunlight during peak hours. The movable nature of these shading studs allows for dynamic control over solar exposure, enabling occupants to tailor their environment based on specific needs and times of the day.

Benefits of Vertical Shading Systems:

- **Solar Control:** The vertical shading systems provide an effective means of solar control, preventing the intrusion of direct sunlight into living spaces during undesirable hours.
- **Thermal Comfort:** By minimizing solar heat gain, the shading systems contribute to improved thermal comfort within the buildings, ensuring habitable conditions even during peak sunlight hours.
- **Energy Efficiency:** Reduced reliance on artificial cooling systems is achieved through the natural shading provided by the vertical studs, promoting energy efficiency and sustainability

Green Roof and Green Wall Interventions:

In a holistic approach to sustainable design, all flat roof blocks with black roofs were transformed into green roofs. This strategic shift not only aids in reducing the urban heat island effect but also enhances the energy efficiency of the buildings. Additionally, the southern facades of the social housing blocks and the single-floor buildings along Via Leone Sinigaglia were transformed into green walls. These interventions not only improve the microclimatic conditions but also contribute to the overall aesthetic quality of the area.

Site Key Issues

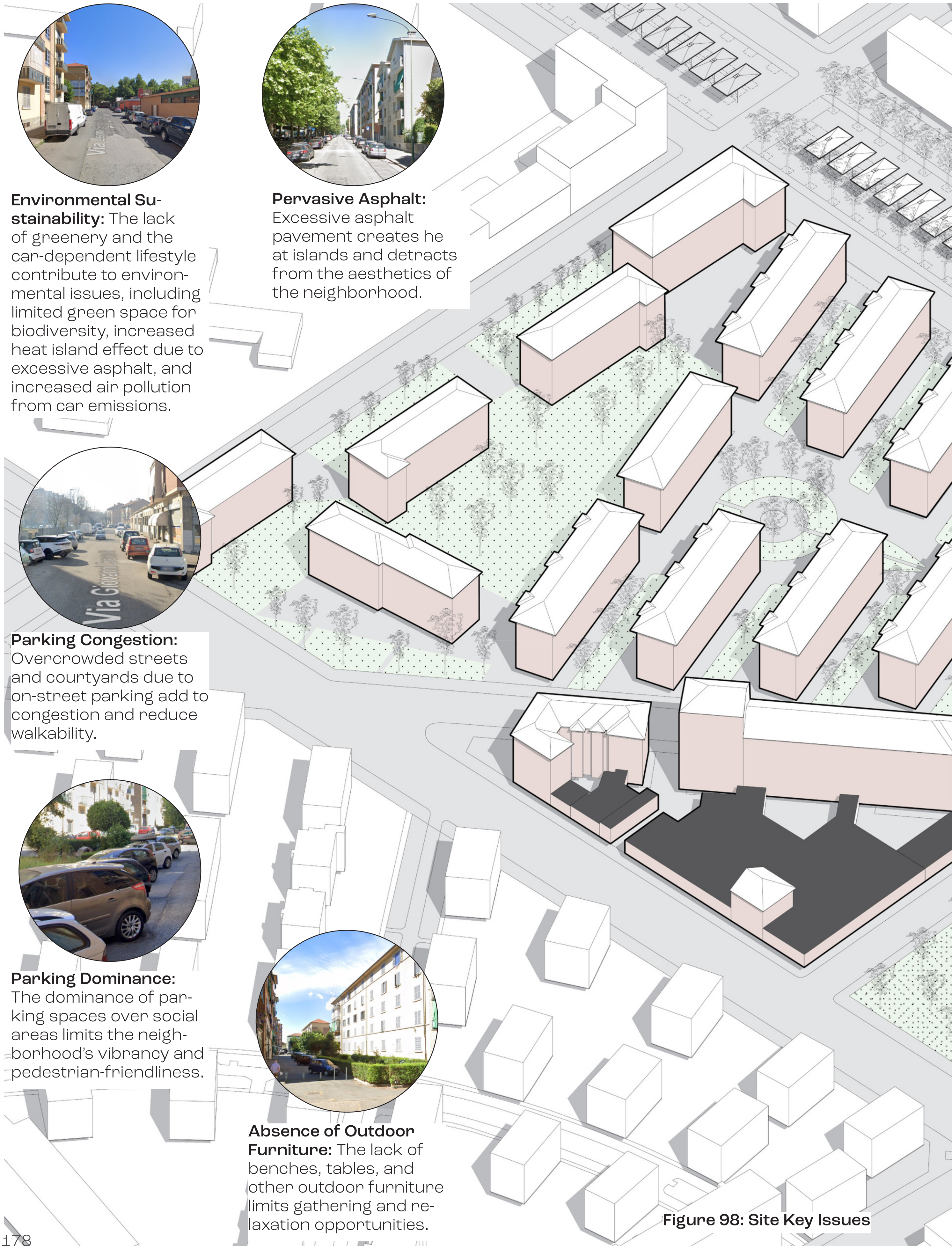
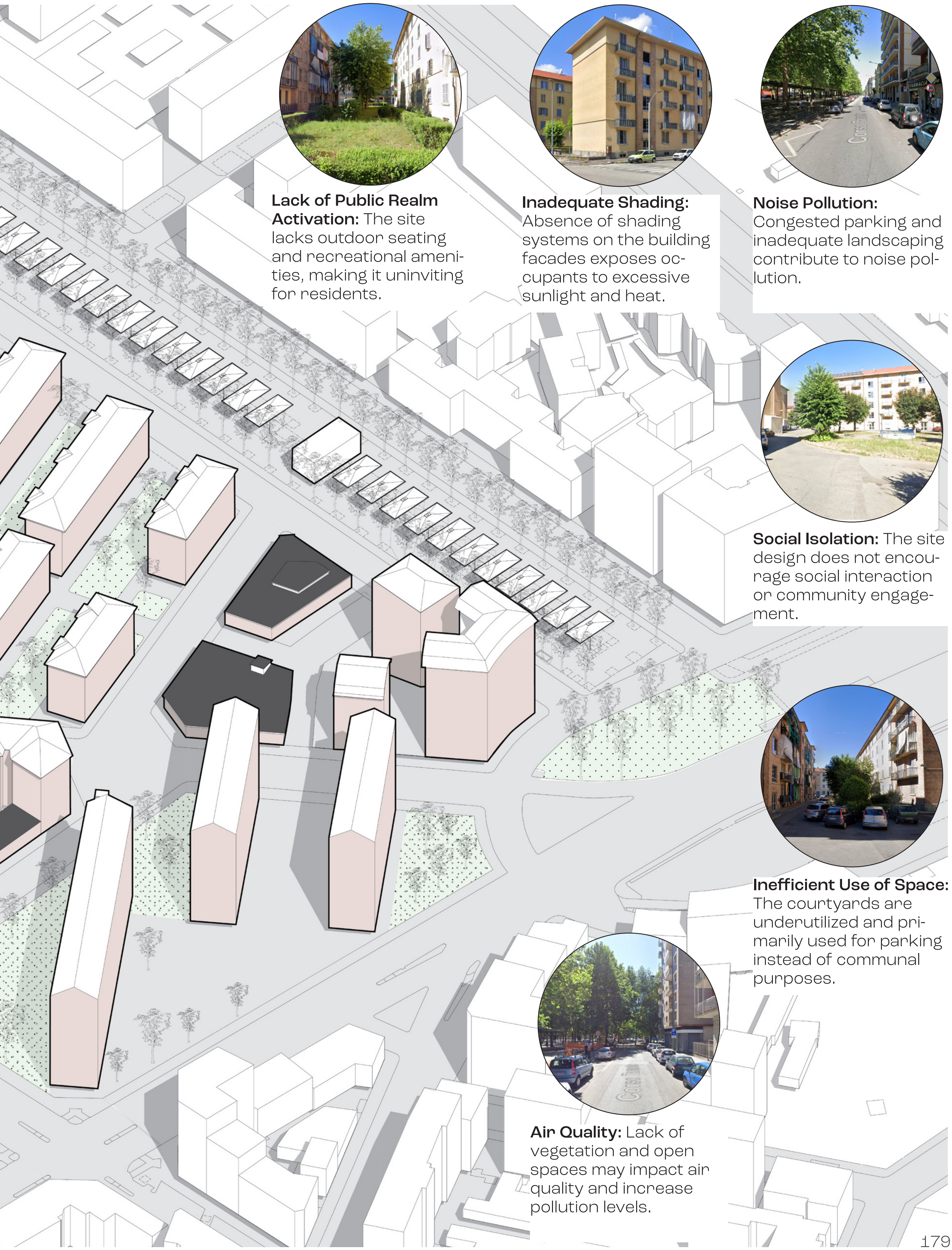


Figure 98: Site Key Issues



Lack of Public Realm Activation: The site lacks outdoor seating and recreational ameni-ties, making it uninviting for residents.

Inadequate Shading: Absence of shading systems on the building facades exposes oc-cupants to excessive sunlight and heat.

Noise Pollution: Congested parking and inadequate landscaping contribute to noise pol-lution.

Social Isolation: The site design does not encou-rage social interaction or community engage-ment.

Inefficient Use of Space: The courtyards are underutilized and pri-marily used for parking instead of communal purposes.

Air Quality: Lack of vegetation and open spaces may impact air quality and increase pollution levels.

Phase I Interventions


White asphalt
Tactical urbanism
Pervious planting zones
Permeable pavement
Colored asphalt

Phase II Interventions

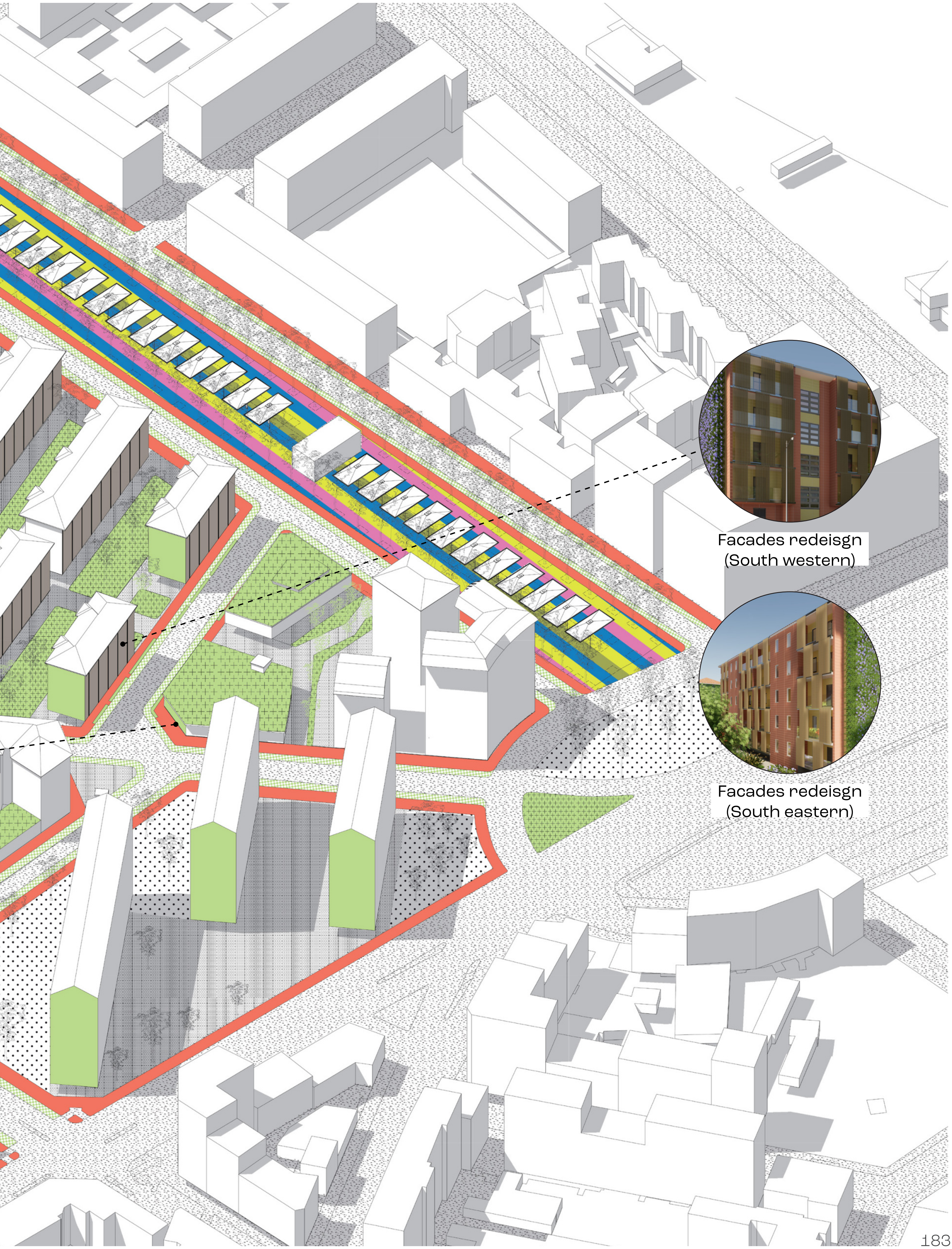
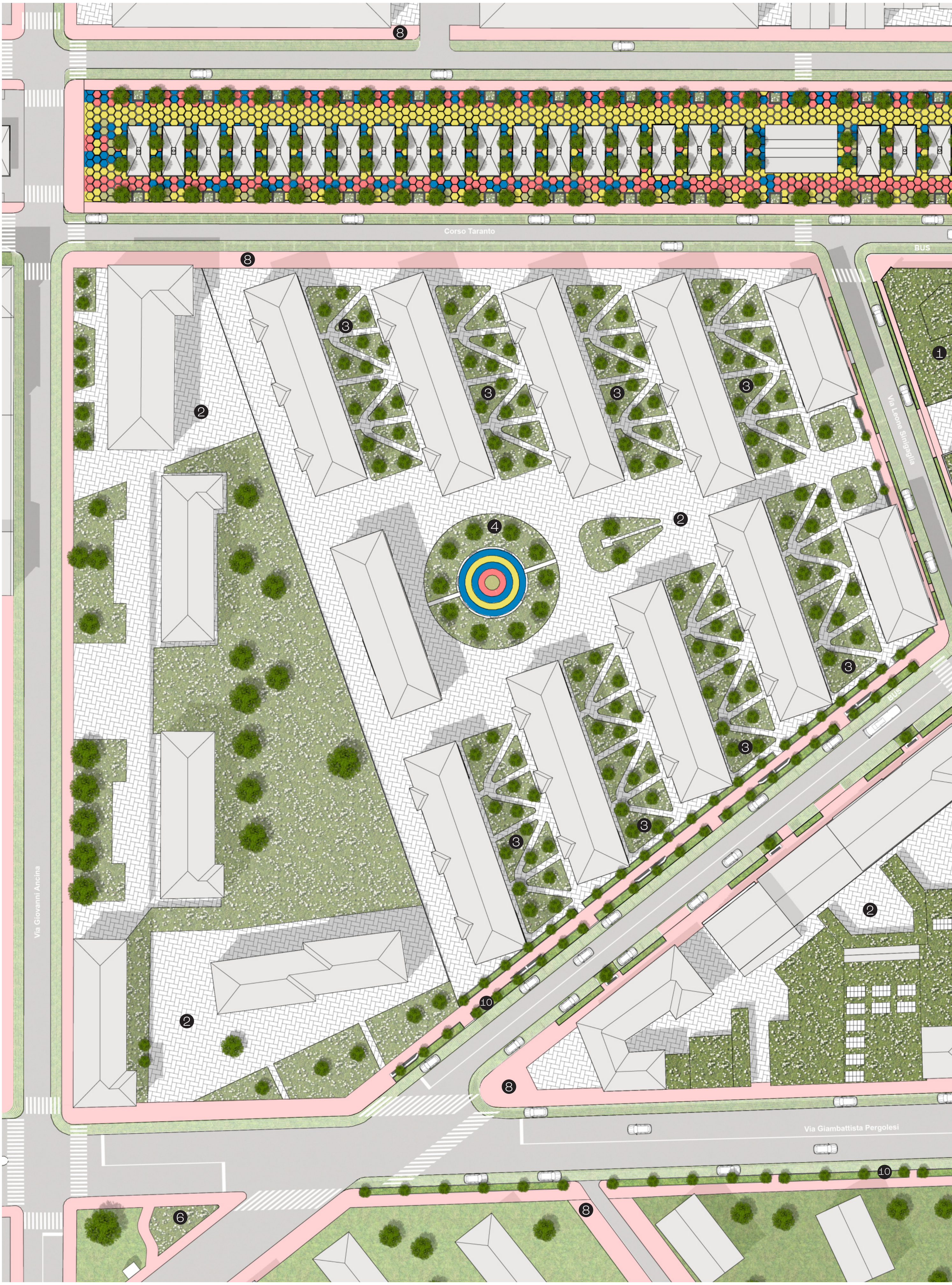

Facades redeisgn
(South western)
Facades redeisgn
(South eastern)

Figure 101: Proposed plant species

PLANT	TYPE	GROWTH/year	DIMENSIONS	WATER DEMAND	TARGETS	COMMENTS
1. Plumbago blu	Shrub	5-10cm	H=2m	Moderate / well-drained soil	Butterflies	Moderately frost resistant
2. Concha-california-lilac	Shrub	10-25cm	H=3m	Well-drained soil	Bees / Butterflies	Drought resistant
3. Viburnum Tinus	Shrub	45cm	H=3m	Adaptable to different soil	Butterflies	Moderately frost resistant
4. Acer Giapponese	Tree	15cm	H=3-10m	Moderate	Bees / Butterflies	Frost resistant
5. Jasminum polyanthum	Shrub	15-30cm	H=5m	Well-drained soil	Bees / Butterflies	Moderately frost resistant
6. Field Scabious	Perennial	10-25cm	H=1m	Well-drained soil	Bees / Butterflies	Moderately frost resistant
7. Bigleaf Hydrangeas	Shrub	5-10cm	H=1m	Moist / Well-drained soil	Bees	Moderately frost resistant
8. Acer platanoides	Tree	15cm	H=20-30m	Moderate	Bees / Butterflies	Frost resistant
9. Magnolia Kobus	Tree	20-30cm	H=10m	High	Bees / Butterflies	Moderately Frost resistant
10. Nyssa sylvatica	Tree	30-60cm	H=15-25m	Thrives in moist, acidic soils.	Birds	Pest / frost resistant

PLANT	TYPE	GROWTH/year	DIMENSIONS	WATER DEMANDT	ARGETS	COMMENTS
11. Lythrum salicaria	Shrub	10-15cm	H=1.5m	Moderate / Moist soil	Bees / Butterflies	Moderately frost resistant
12. Helianthus annuus	Perennial	10-15cm	H=3m	Moderate / well-drained soil	Bees	Sensitive to frost
13. Clematis	Climber	30-45cm	H= >6m	Well-drained soil	Bees / Butterflies	Moderately frost resistant
14. Lantana	Perennial	10-25cm	H=2m	Well-drained soil	Butterflies	Sensitive to frost
15. Lavender	Herb	20-40cm	H=1m	Well-drained soil	Bees / Butterflies	Moderately frost resistant
16. Populus nigra italica	Tree	90cm	H=30m	Thrives in moist soils Drought tolerant	Birds / Butterflies	Flood / frost resistant
17. Pomegranate	Shrub	xxcm	H= 5m	Well-drained soil	Birds / Insects	Moderately frost resistant
18. Parthenocissus	Climber	100-300cm	H= >20m	Adaptable to different soil	Birds	Moderately frost resistant
19. Bougainvillea	Climber	15-30cm	H= 5m	Well-drained soil	Butterflies	Sensitive to frost
20. Ginkgo	Tree	30-60cm	H=30m	Low - Moderate	Birds, bees, butterflies	Pest/diseases resistant


Corso Taranto
BUS
Via Leone Sinigaglia
Via Giovanni Ancina
Via Giambattista Pergolesi

LEGEND

1. Green roofs
2. Permeable paving
3. Courtyards
4. Public square / Playground
5. Reclaimed Frontage
6. Gardens (Flower beds)
7. Taranto Martket (Tactical urbanism area)
8. Sidewalks / Cyclist paths
9. Parking areas with permeable pavings
10. Bioswales

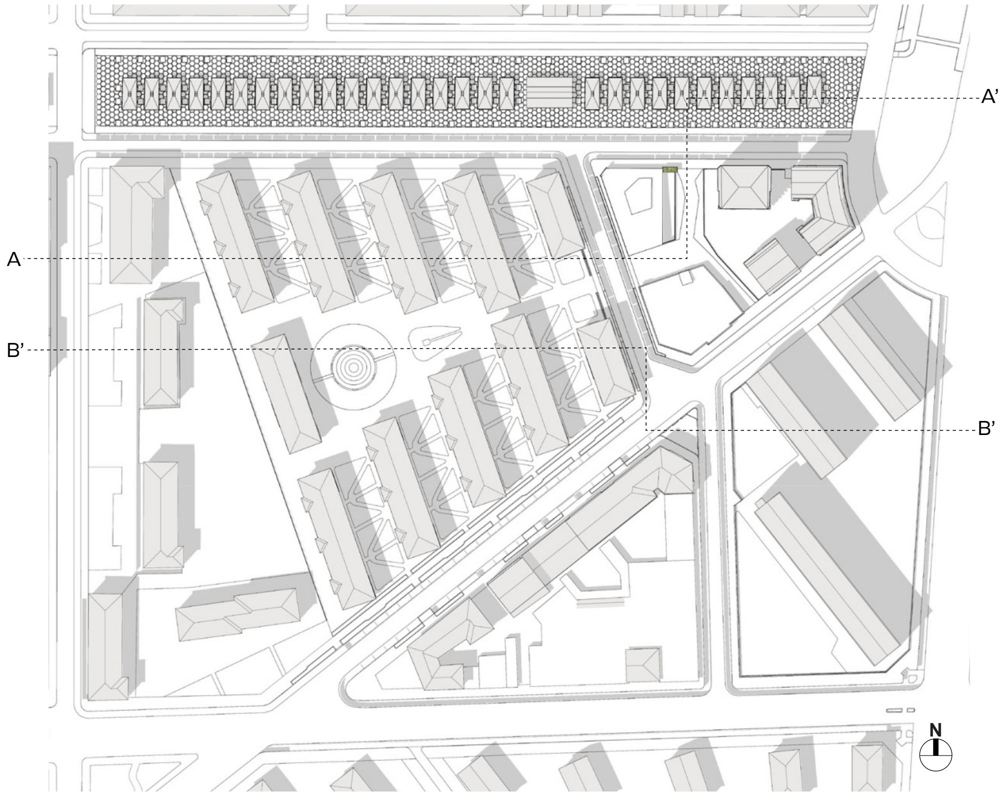
Figure 102: Masterplan

Scale 1:10000

N

Section AA’

Section BB’



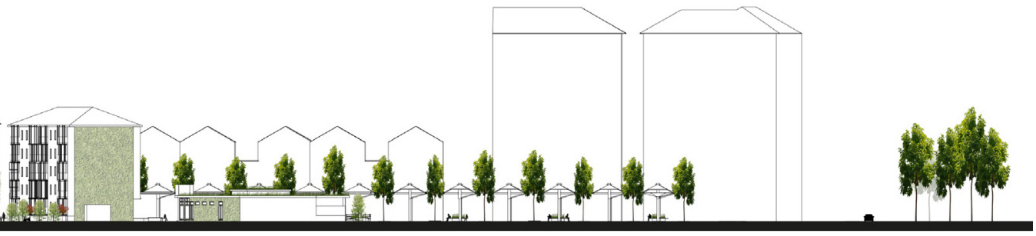


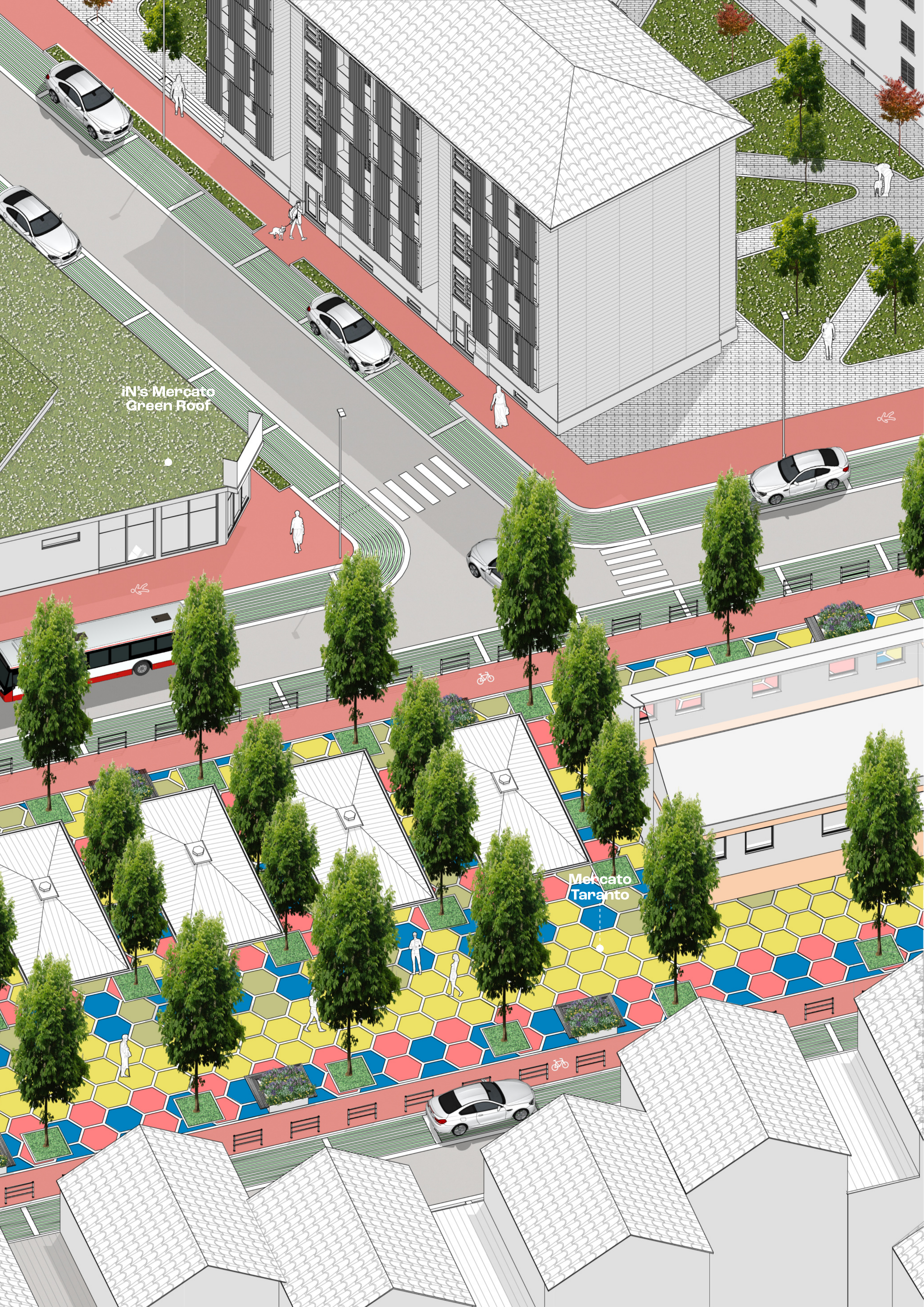
Figure 103: Neighbourhood sections
Scale 1:10000

Axonometry of Corso Taranto

Before intervention

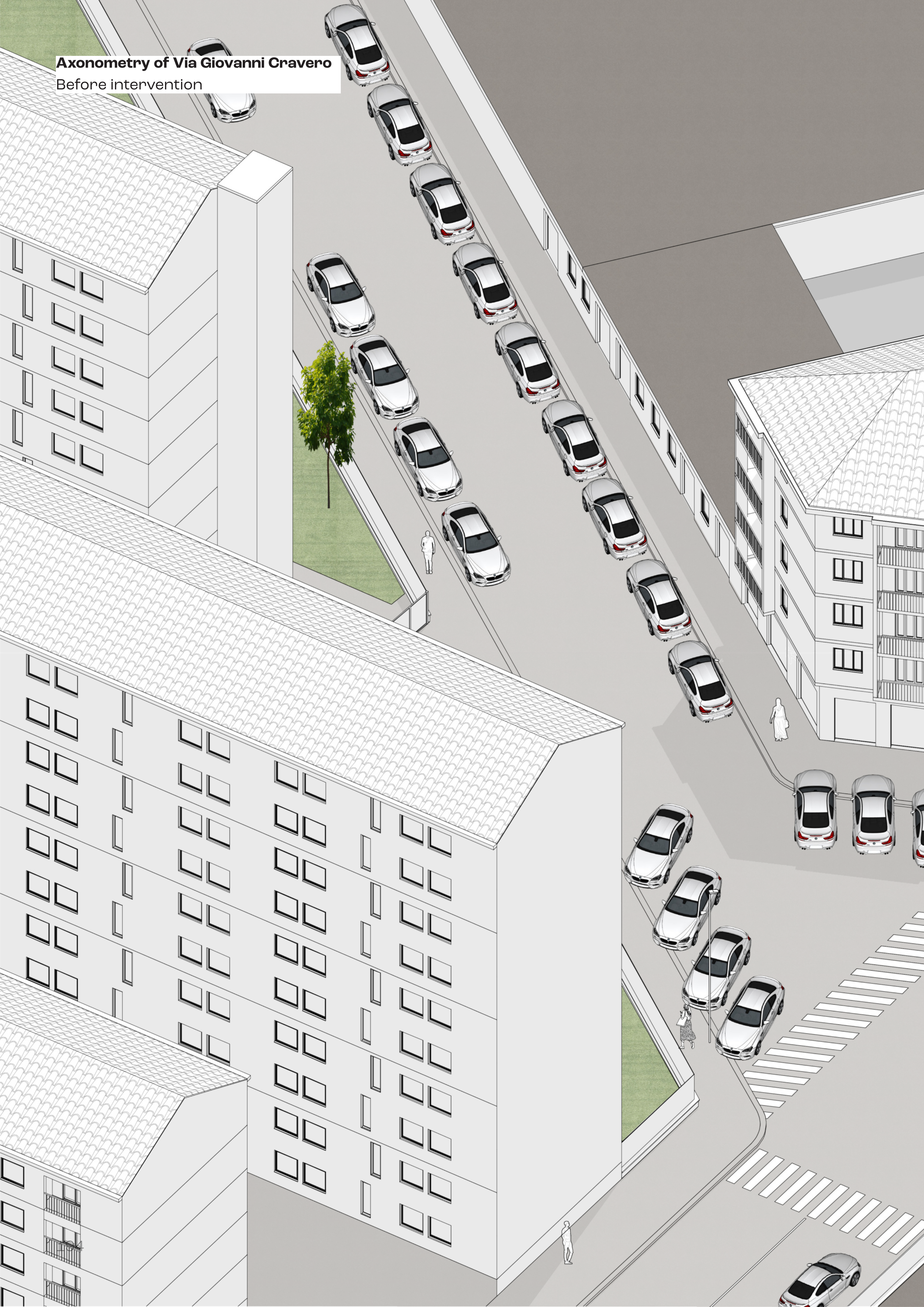

iN's Mercato
Mercato
Taranto

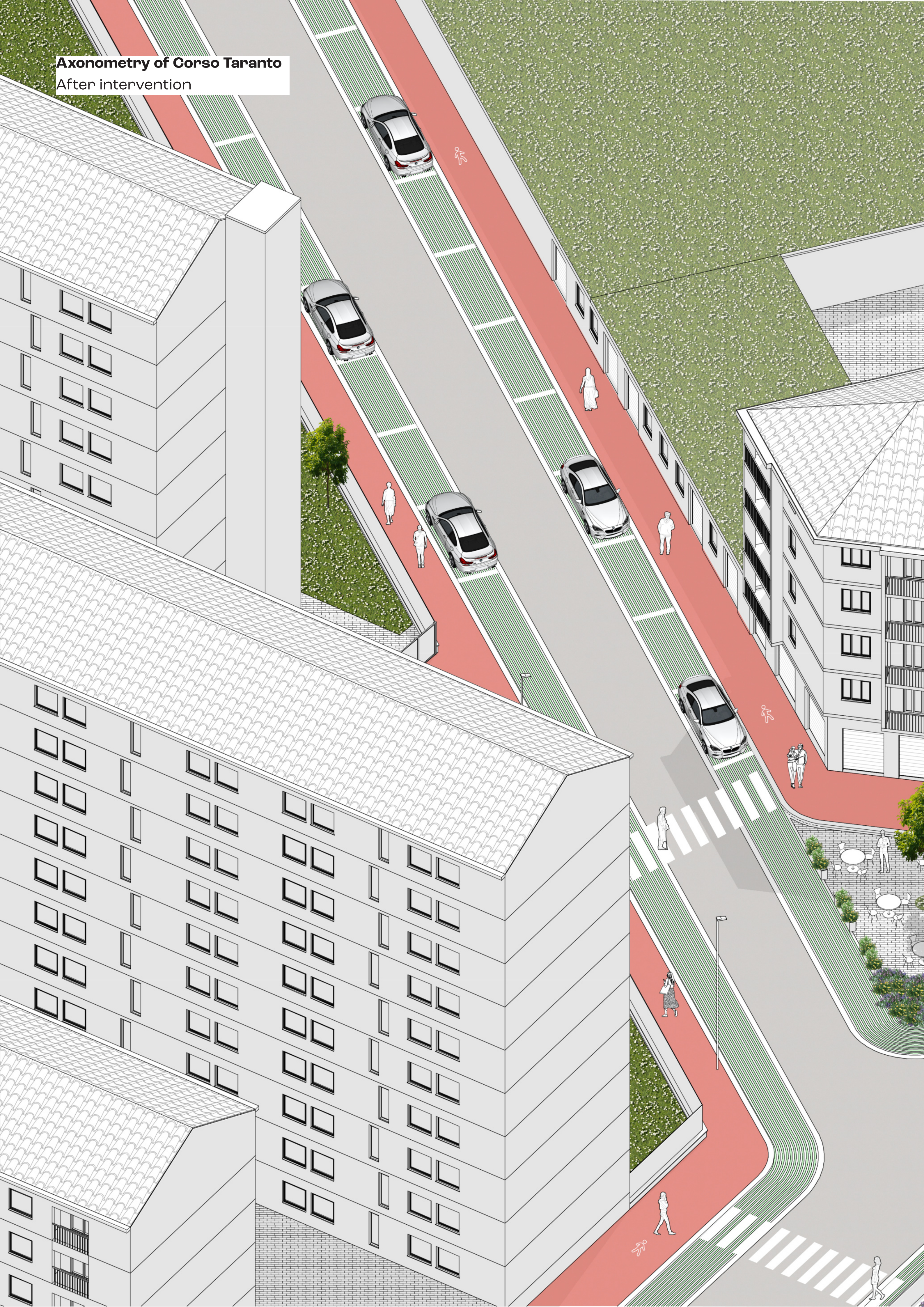
Figure 105: Axonometry of Corso Taranto
After intervention


iN's Mercato
Green Roof
Mercato
Taranto

Axonometry of Via Giovanni Cravero

Before intervention





Axonometry of Corso Taranto

After intervention

Axonometry of Via Leone Sinigaglia

Before intervention

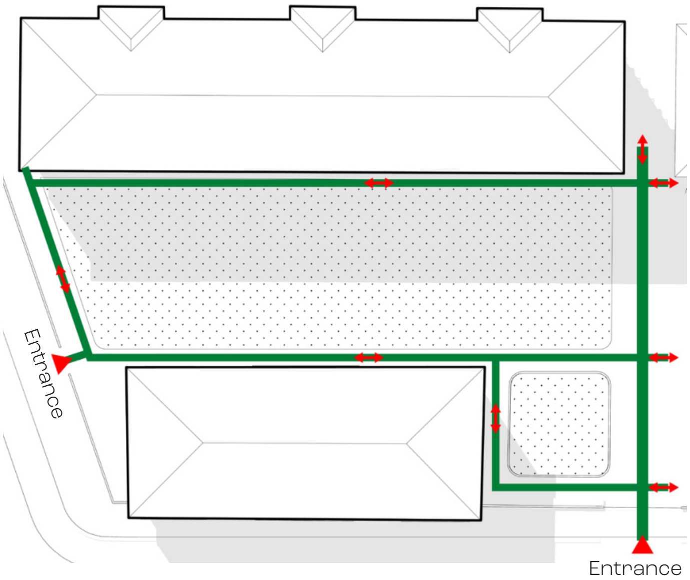

iN's Mercato
Best store

Axonometry of Via Leone Sinigaglia
After intervention

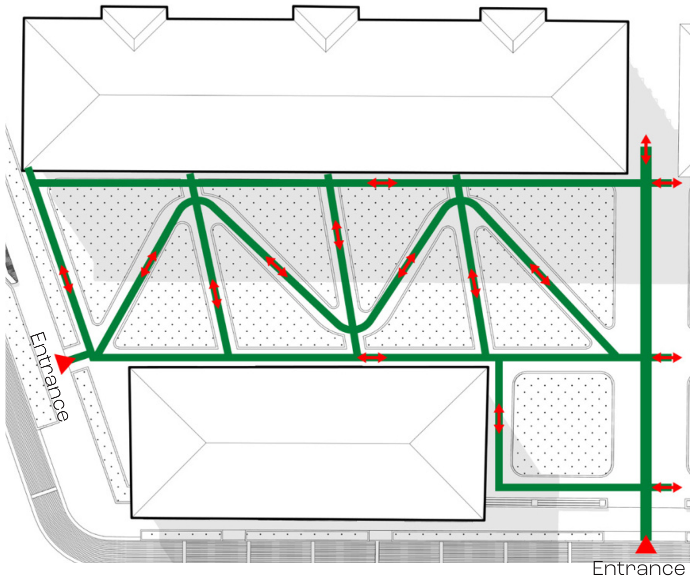

IN's Mercato
Best store

Courtyards Redesign

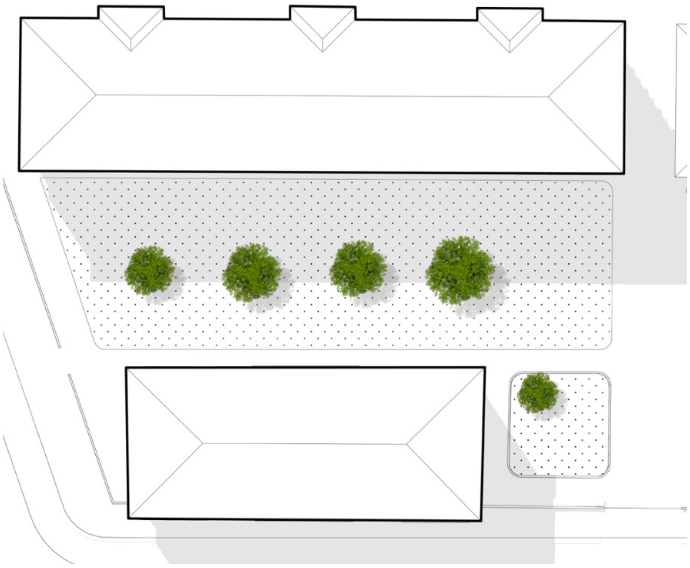
Courtyards redesign strategies



Circulation: Before

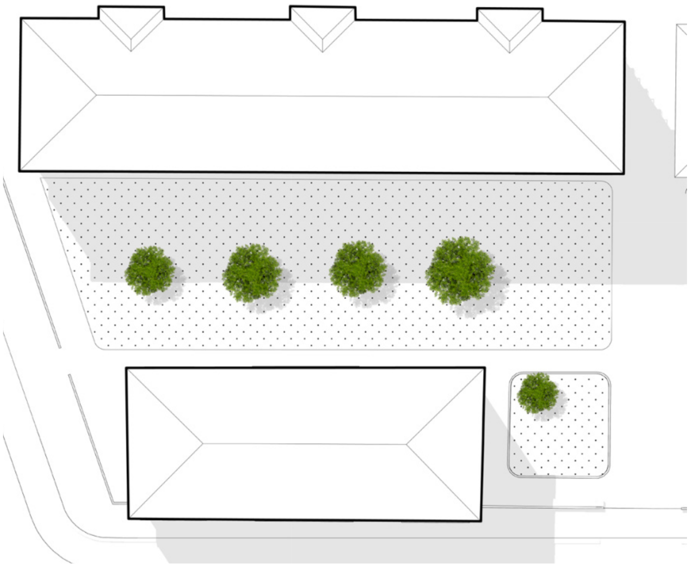


Circulation: After



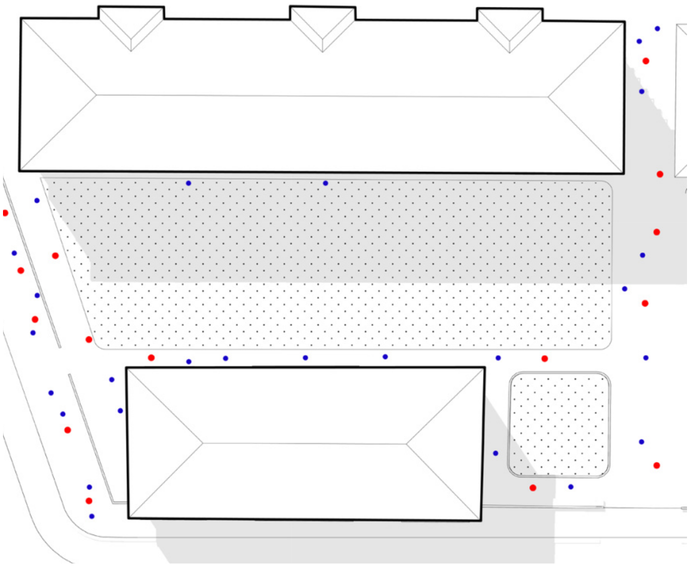
Green spaces: Before

Green spaces: After

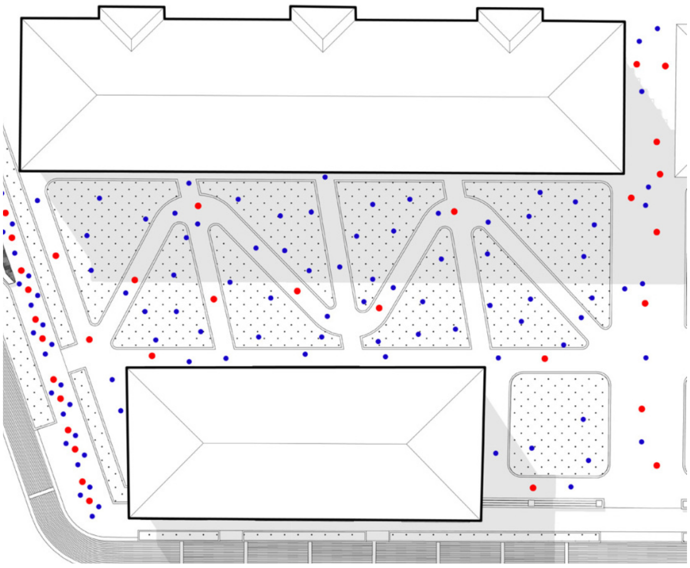


Seatings: Before

Seatings: After



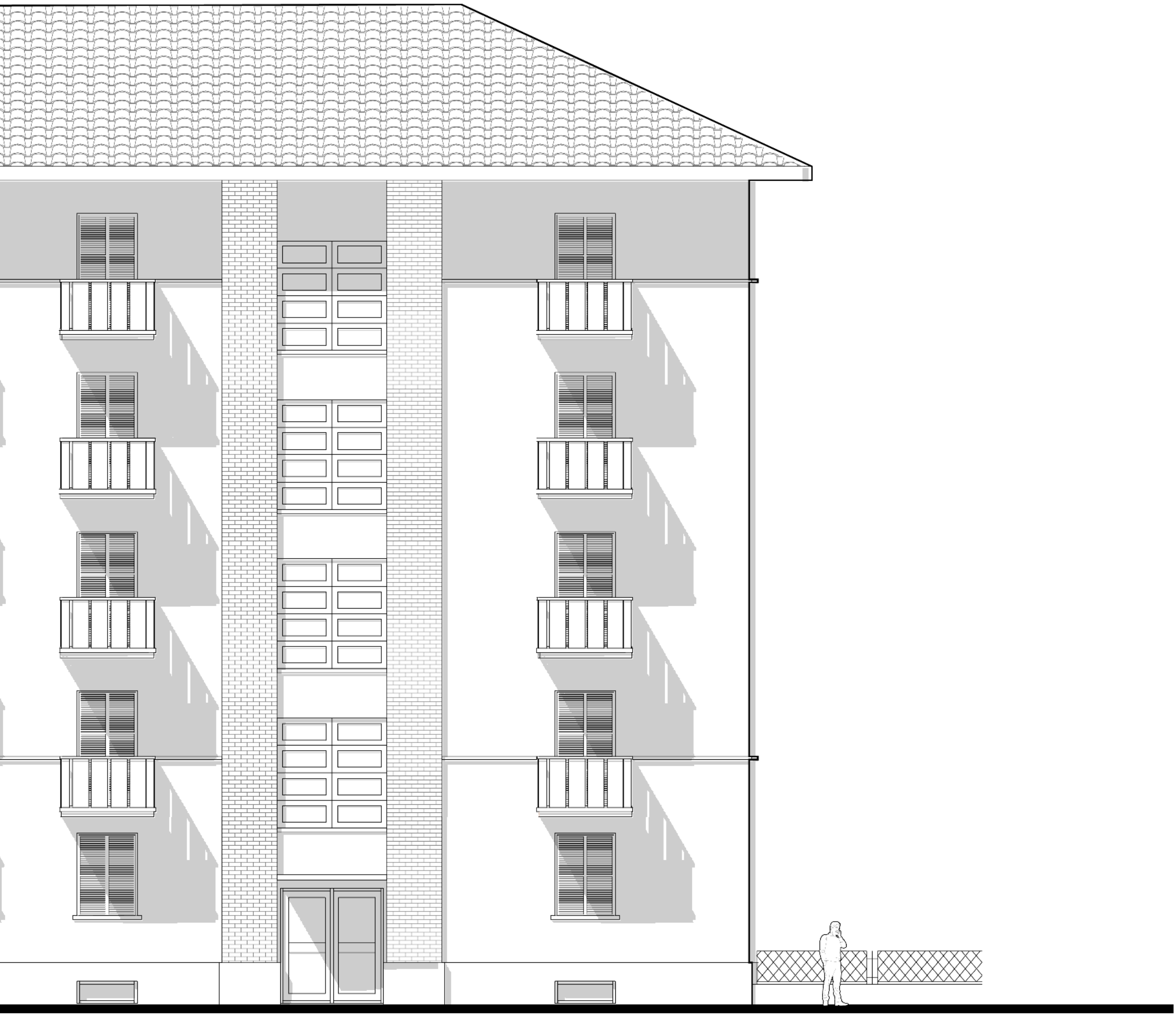
Spartial colonization: Before



Spartial colonization: After

Building facade (SW)

Before



Scale 1:100

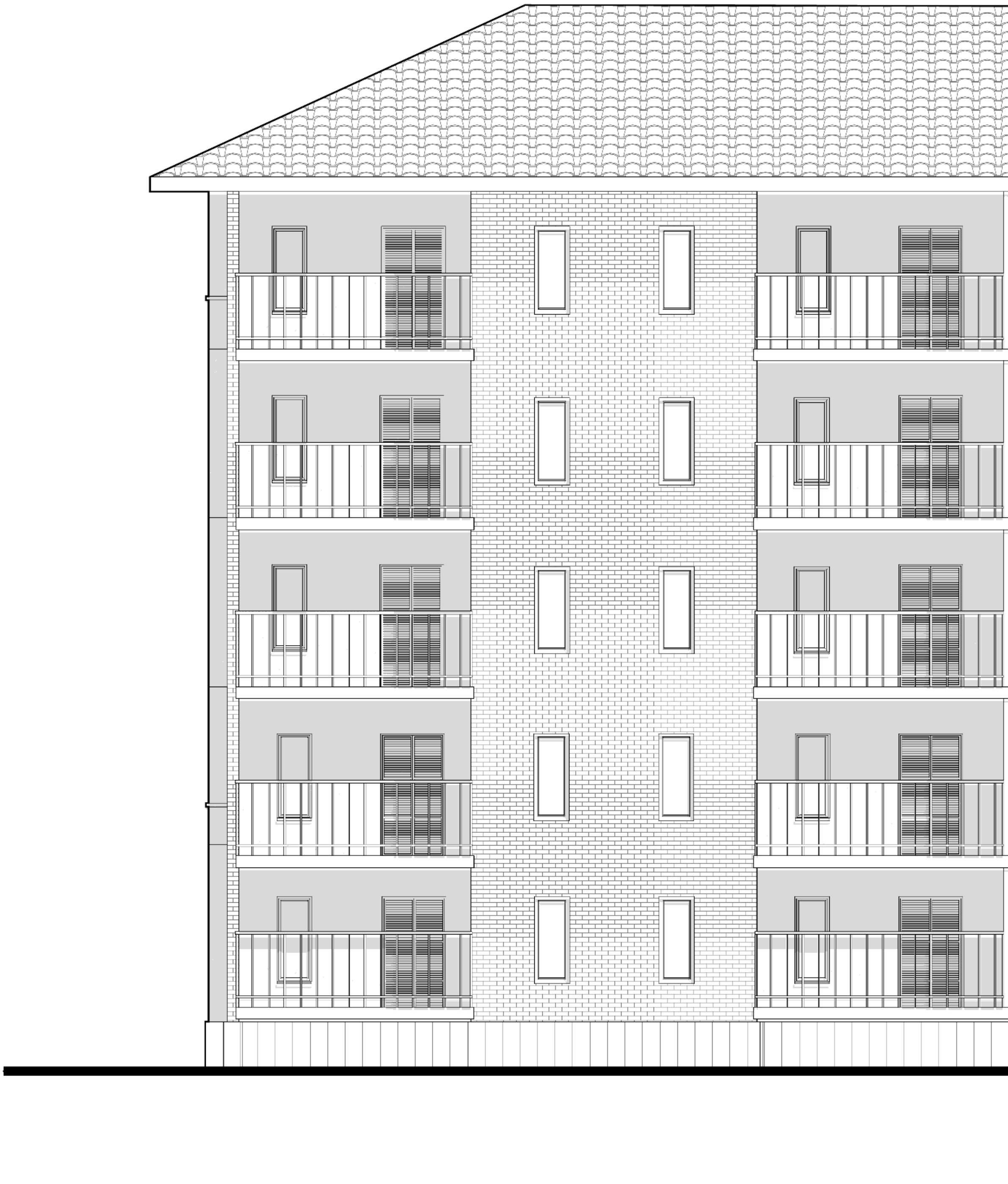
Building facade (SW)

After

Scale 1:100

Building facade (SE)

Before



Scale 1:100

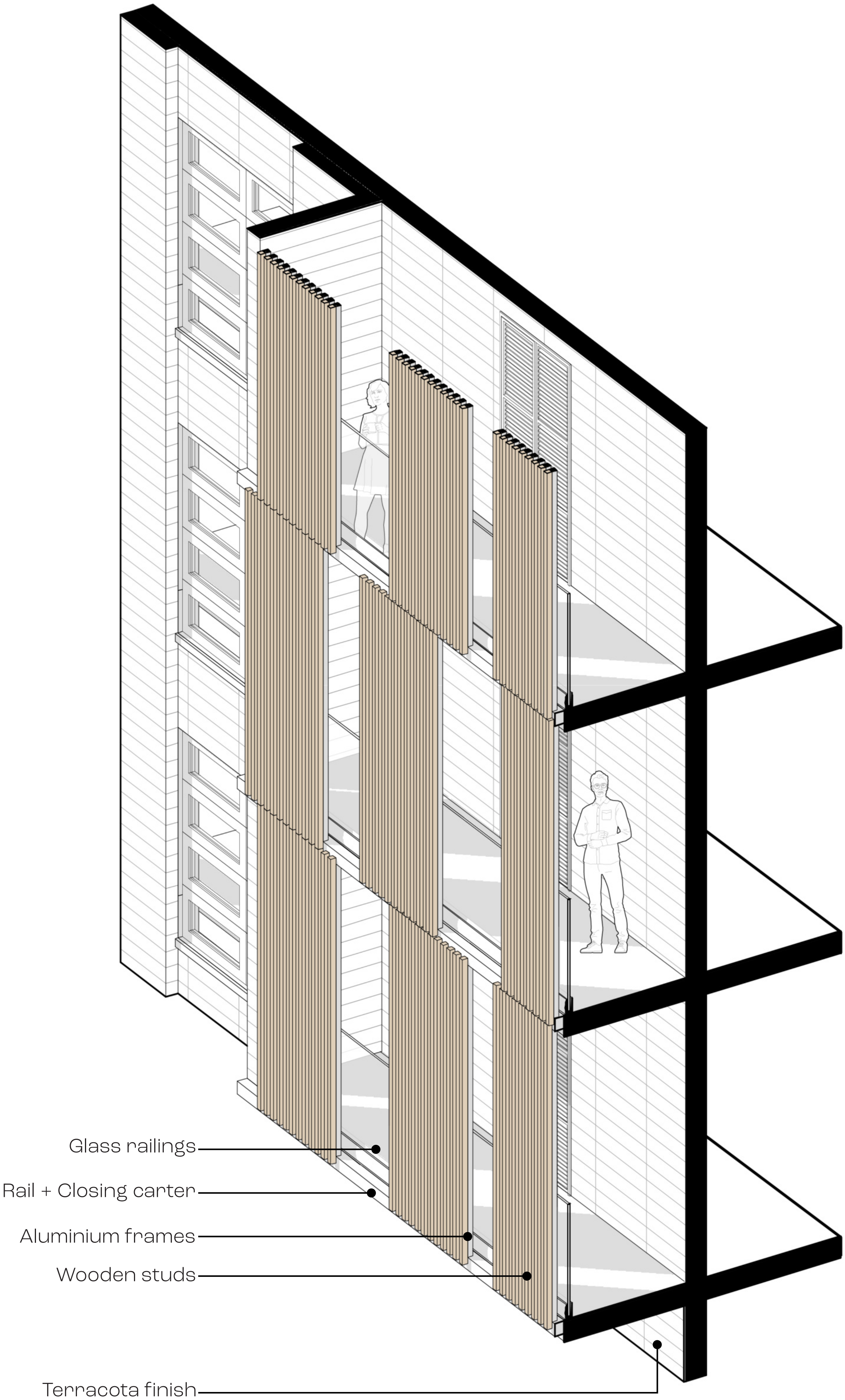
Building facade (SE)

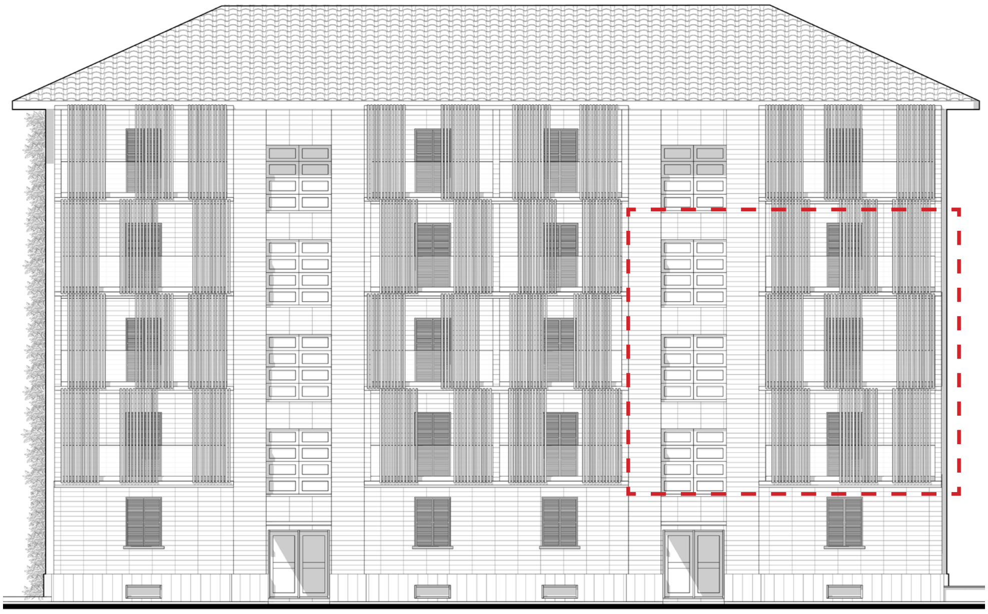
After

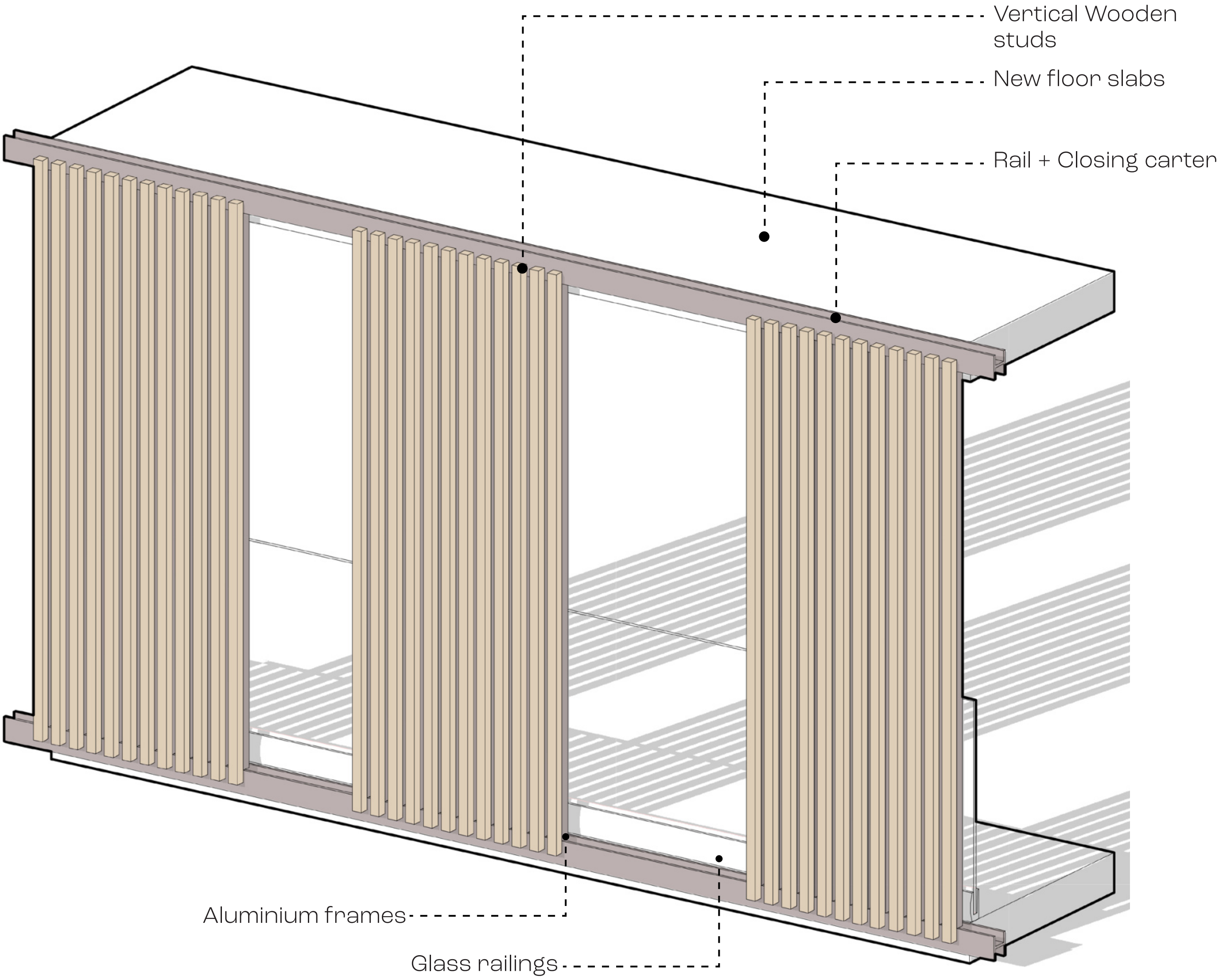
Scale 1:100

Building facade Excerpt (South Western)

After



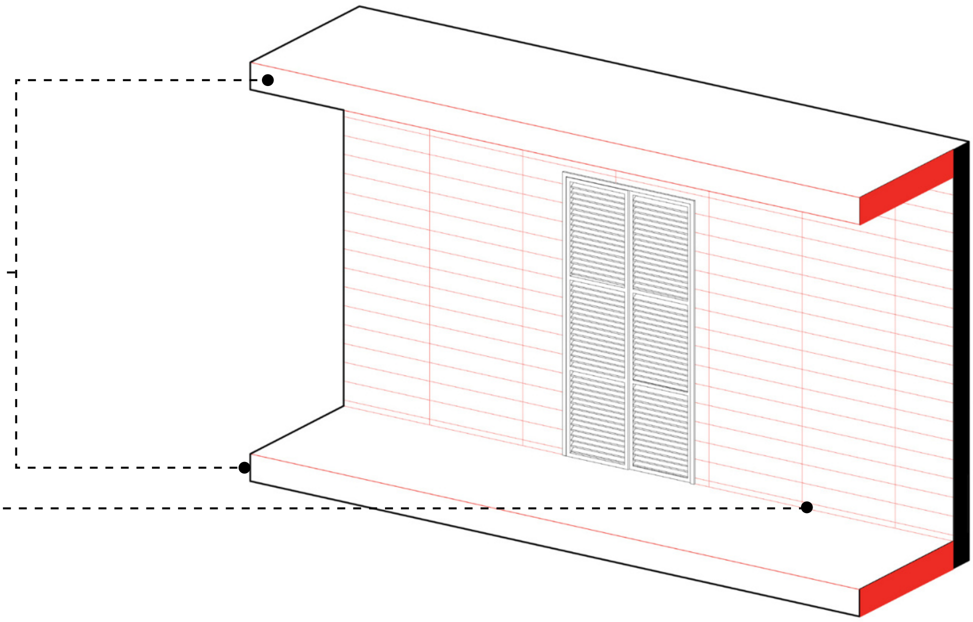


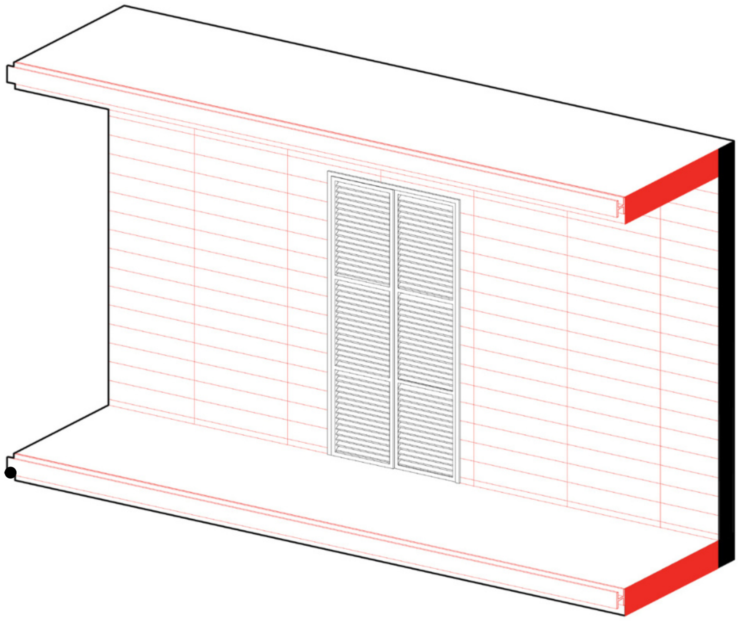


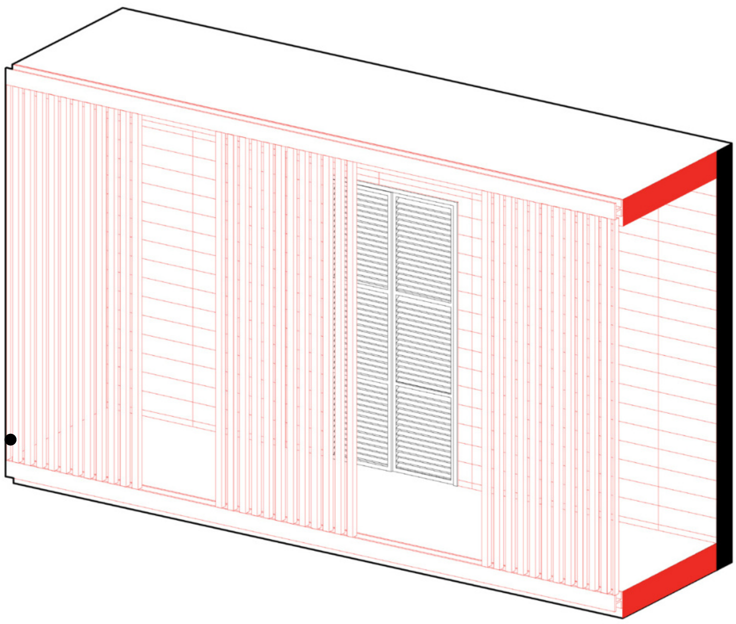
Vertical Wooden studs
New floor slabs
Rail + Closing carter
Aluminium frames
Glass railings

Facade transformation

Assembling steps

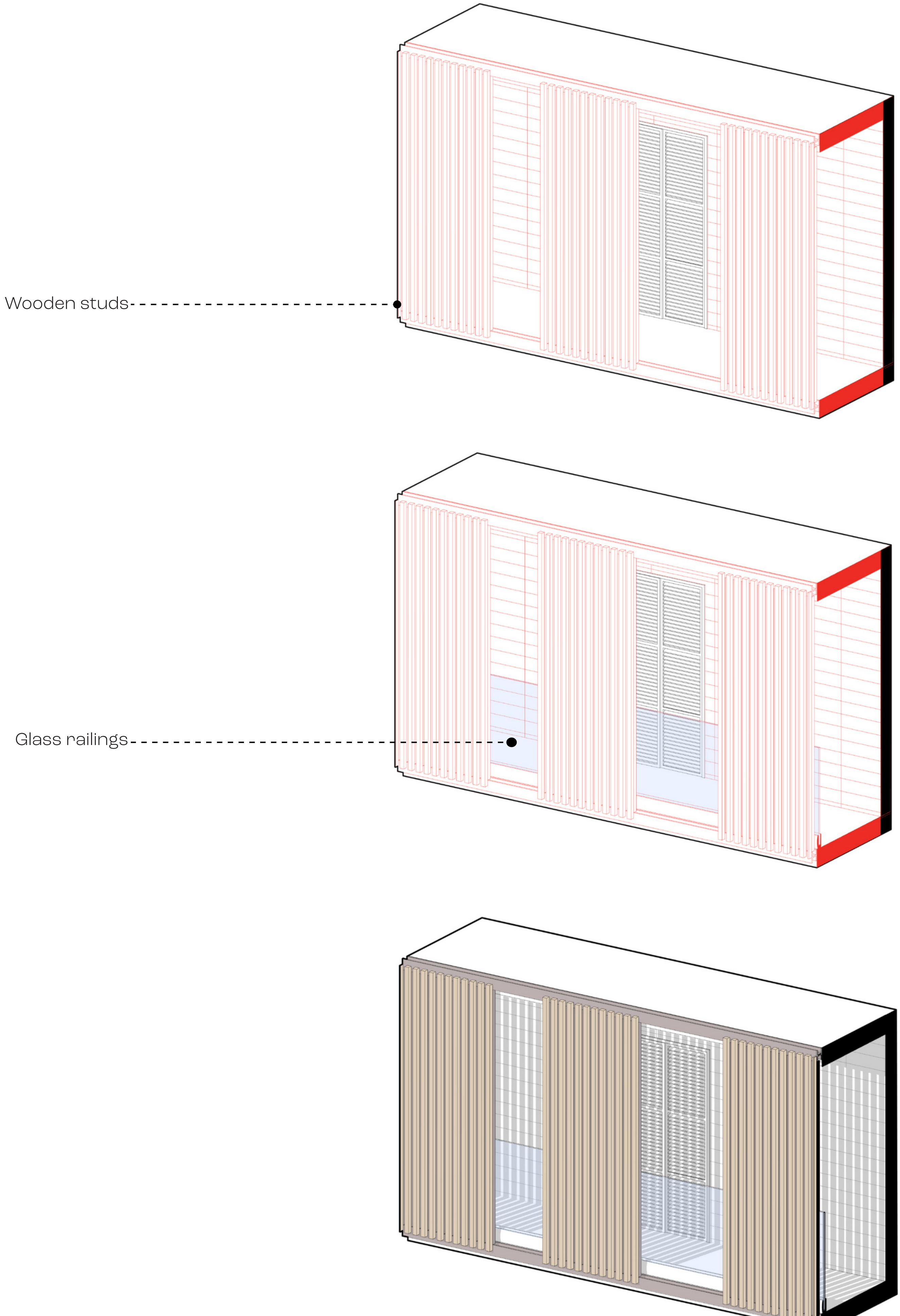






Additions

Existing



Facade Excerpt

Additions
Existing


pears
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CONCLUSION

Conclusion

The research embarked upon in this thesis, "Environmental Regeneration through Green Infrastructure: A Case Study of Regio Parco in Turin," has provided comprehensive insights into the multifaceted realm of green infrastructure, with a focus on its implementation and effectiveness in urban regeneration. The investigation sought to address several key research questions, spanning the definition and typologies of green infrastructure, the tools and strategies enhancing its design, methods of valuation, the effectiveness of its implementation, and the sociocultural impacts on community dynamics. The following paragraphs summarize the key findings, reflect on the research process, and provide recommendations for future work.

Meaning of "Green Infrastructure":
The exploration of the term "Green Infrastructure" delved into its definitions, origins, frameworks, and typologies. Green infrastructure emerged not merely as a physical manifestation of natural elements within urban spaces but as a holistic concept that integrates ecological, social, and economic dimensions. It was revealed as an evolving discipline, shaped by various frameworks and typologies that adapt to the specific needs and characteristics of urban environments.

Innovative Tools and Strategies:
The investigation into innovative tools and strategies showcased a diverse array of approaches to enhance the design and implementation of green infrastructure projects. From green roofs and walls to permeable pavements and infiltration systems, the case studies illuminated how thoughtful integration of these elements could mitigate urban heat island effects, improve air quality, and foster a more sustainable urban environment.

Valuation Methods:
The examination of valuation methods for green infrastructure projects underscored the economic and environmental benefits associated with such interventions. The studies on cost-benefit analysis revealed that the positive returns on investment make a compelling case for the inclusion of green infrastructure in urban planning and development. Economic valuation emerged as a critical aspect, emphasizing the need to demonstrate the tangible advantages for stakeholders and decision-makers.

Effectiveness of Implementation:
The effectiveness of green infrastructure implementation in urban regeneration was evidenced by the transformation of the Quartiere S1 neighborhood in Regio Parco, Turin. Changes in outdoor spaces, courtyards, and building facades were not merely physical alterations but catalyzed a shift in community dynamics. The redesign contributed to increased social interactions and fostered a sense of community, highlighting the social benefits intertwined with environmental considerations.

Recommendations for Future Work

While this thesis has contributed significantly to the understanding of green infrastructure in urban regeneration, avenues for future research remain abundant. Firstly, a more in-depth study of the economic valuation of green infrastructure is warranted, considering the substantial costs associated with implementation. Future research should scrutinize the financial aspects more comprehensively to provide urban planners and policymakers with nuanced insights into the economic feasibility of such projects. Additionally, the need for a more efficient microclimate analysis tool was identified. While ENVI-met software proved valuable, a future development or research into a tool that reduces simulation time and costs would be instrumental for broader applications. This is particularly important as urban regeneration projects often operate within tight budgets and timelines.

Finally, the long-term impacts of green infrastructure on combating future urban heat island effects should be closely monitored and studied. Quantifying the extent to which green walls, green roofs, and other interventions contribute to sustained temperature reductions over time will provide valuable information for future urban planning endeavors.

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