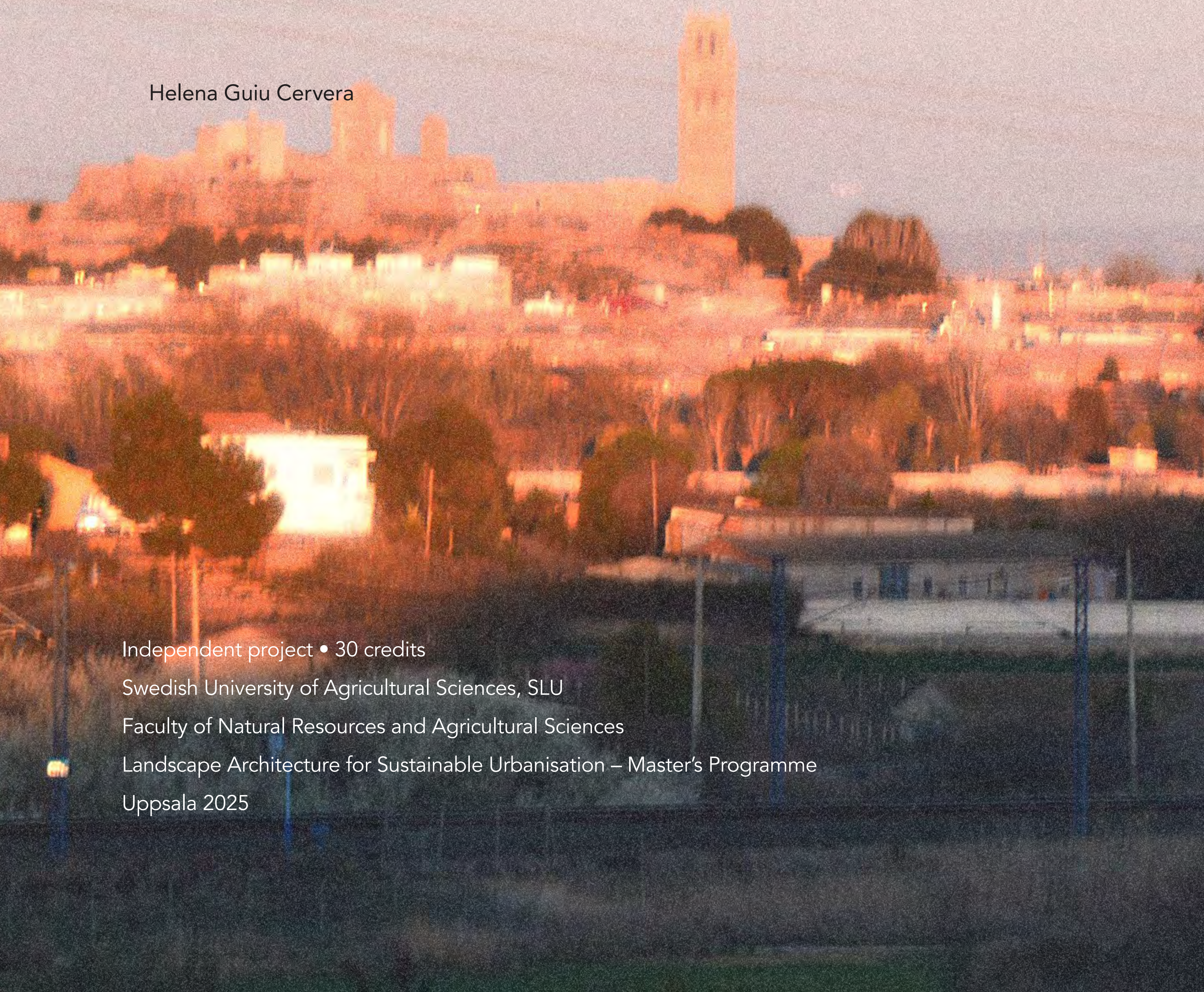
Exploratory Study of a Rehabilitative Heat-Resilient Green-Blue Infrastructure

Case Study: Lleida, Catalonia, Spain



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EXPLORATORY STUDY OF A REHABILITATIVE HEAT-RESILIENT GREEN-BLUE INFRASTRUCTURE. CASE STUDY: LLEIDA, CATALONIA, SPAIN

ESTUDI EXPLORATORI D'UNA INFRASTRUCTURA VERDA-BLAVA REHABILITADORA I RESILIENT A LA CALOR. CAS D'ESTUDI: LLEIDA, CATALUNYA, ESPANYA

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ABSTRACT

As heat waves intensify, posing significant threats to human health, ecological integrity, and overall urban resilience, city living becomes increasingly challenging. High levels of impervious surfaces exacerbate temperature extremes, while the loss of biodiversity diminishes natural cooling capacities. Recent European restoration policies emphasise the urgent need to create healthier environments for both people and ecosystems, offering a strategic opportunity to integrate ecological rehabilitation into urban heat mitigation efforts. This research investigates the role of landscape architecture in addressing urban heat stress through innovative design and planning strategies that simultaneously enhance resilience and restore novel ecosystems.

This study employs a multi-method approach to explore the intersections of urban heat mitigation, ecological restoration, and landscape planning. The medium-sized city of Lleida, located in northeastern Spain, serves as the case study due to its semi-arid, continental climate and extensive rural-urban interface. The analysis combines geospatial data from Landsat-8 to generate a land surface temperature [LST]heat map with on-site explorations and localised assessments of cooling island compositions. The ESTER 2.0 tool is used to evaluate ecosystem services and compare patch compositions, contributing valuable insights into effective urban cooling strategies.

Findings reveal significant temperature variations of up to 13°C across the urban fabric, with tree-covered areas demonstrating the most pronounced cooling effects. In contrast, industrial zones, abandoned plots, and agricultural fields emerge as critical heat sources. The study underscores the importance of water availability, topography, and landform configurations in facilitating cooling mechanisms such as evapotranspiration and airflow. Jack Ahern's (2011) resilience framework is applied to propose a heat-resilient network that aligns with geomorphological structures, promoting strategic connectivity between existing and rehabilitated green-blue infrastructures. Multiscalar, modular interventions—integrating tree-dominated systems, wind corridors, and sustainable water management—are identified as essential for mitigating urban heat while enhancing ecosystem functionality. However, knowledge gaps persist concerning the characterisation of referent habitat for rehabilitative practices and the potential role of xeric landscapes in urban heat resilience, necessitating further investigation research.

This research highlights the critical role of landscape planning and design in mitigating heat stress and fostering urban resilience. To address the increasing frequency of extreme heat events, planners and designers must adopt a holistic, multi-scalar approach that integrates ecological restoration with adaptive urban strategies. Collaborative efforts between policymakers, ecologists, and local communities are essential to developing sustainable, site-responsive interventions that reduce heat stress and contribute to the long-term ecological and social health of urban environments.

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ABBREVIATIONS

AR	Aspect Ratio
ES	Ecosystem Service
GBI	Green and Blue Infrastructure
HRGBI	Heat-Resilient Green-Blue Infrastructure
PCI	Potential Cooling Intensity
LST	Land Surface Temperature
UFS	Urban Free Spaces
UHI	Urban Heat Island

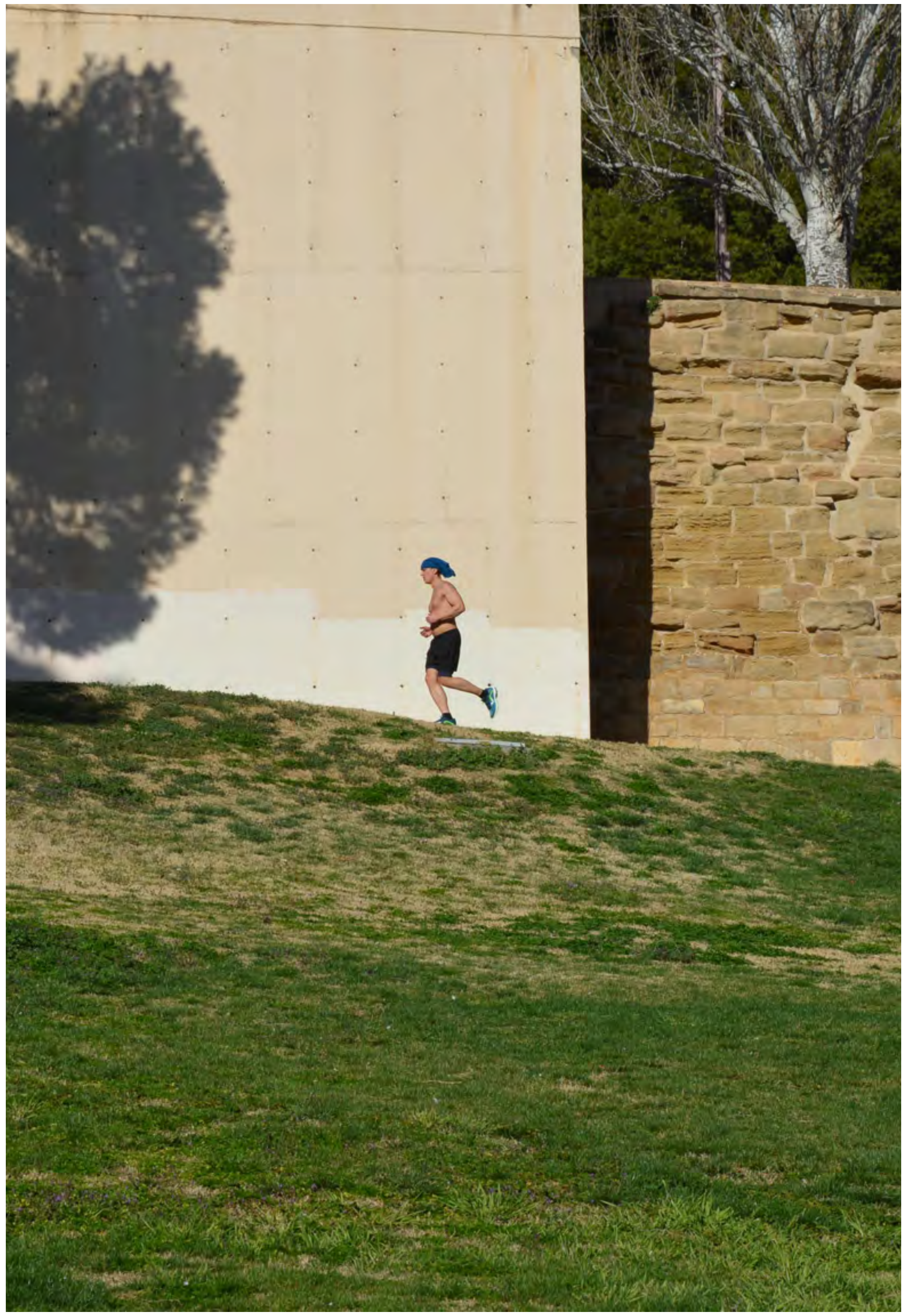


Figure 1.1: A runner on the Seu Vella hill in March 2023 covering his head, a typical action to protect from the sun radiation.

CHAPTER

1

INTRODUCTION – FRAMING THE URBAN HEAT CHALLENGE

1.1 THE HEAT IS ON: WHY THIS STUDY MATTERS

As urban areas face increasing heat stress, proportional and multi-scale actions are essential. While global climate patterns influence overarching temperature trends, persistent new temperature records (Copernicus ECMWF & Copernicus EU 2024) underscore the inadequacy of these actions. Since the first climate change report in 2015, considerable efforts have been made to reduce anthropogenic emissions to tackle global warming (IPCC 2018). However, the reality of heat stress is most acutely experienced at the local level, where microclimatic factors such as solar radiation, humidity, and wind flow converge to influence thermal comfort directly (Negev et al. 2020), and live species take action to adapt (Figure 1.1).

Landscape planning and design emerge as powerful perspectives in addressing these challenges by fostering resilience and justice. By focusing on the local scale, they can respond to the specificities of microclimatic dynamics and urban contexts, which global interventions often overlook. This research explores how these fields can provide transformative insights for urban heat mitigation, integrating resilience and ecological justice as guiding principles.

1.2 UNMASKING THE SILENT KILLER: UNDERSTANDING HEAT STRESS

Heat waves, which have become more frequent and severe since the 1950s (Rasilia et al. 2019; Basarin et al. 2020), pose significant risks to society, ecosystems, and the economy (Hintz et al. 2018). Although there is no agreed-upon definition of heat waves, they are generally understood as prolonged periods of exceptionally high atmospheric heat stress that alter behaviour patterns (Robinson 2001). Due to their association with high mortality rates (Robinson 2001; Basarin et al. 2020; García 2022), heat waves are known as "silent killers" and disproportionately affect vulnerable populations.

Current responses to heat waves typically rely on behavioural adaptations (Basarin et al. 2020), such as avoiding outdoor activities during peak heat hours or looking for shading in public spaces, as Figure 1.2 illustrates. Heat health warning systems [HHWS] are employed to initiate public health interventions, yet these often emphasise individual responsibility, reinforcing societal inequalities. Access to resources like air conditioning and private transportation can mitigate heat risks for those who can. At the same time, vulnerable populations—such as those experiencing homelessness, outdoor workers, or those with pre-existing health conditions—are left at heightened risk risks (Anguelovski & Corbera 2023; Keith & Meerow n.d.). The methods for setting heat thresholds[1] (Basarin

1 According to Basarin et al. (2020), the threshold calculation that is most used is the 98th percentile of June to August of the previous ten years, also used in Catalonia (Meteocat 2023). However, the AEMET uses the 95th percentile of the June to August temperatures between 1971 and 2000 in Spain (AEMET 2019).

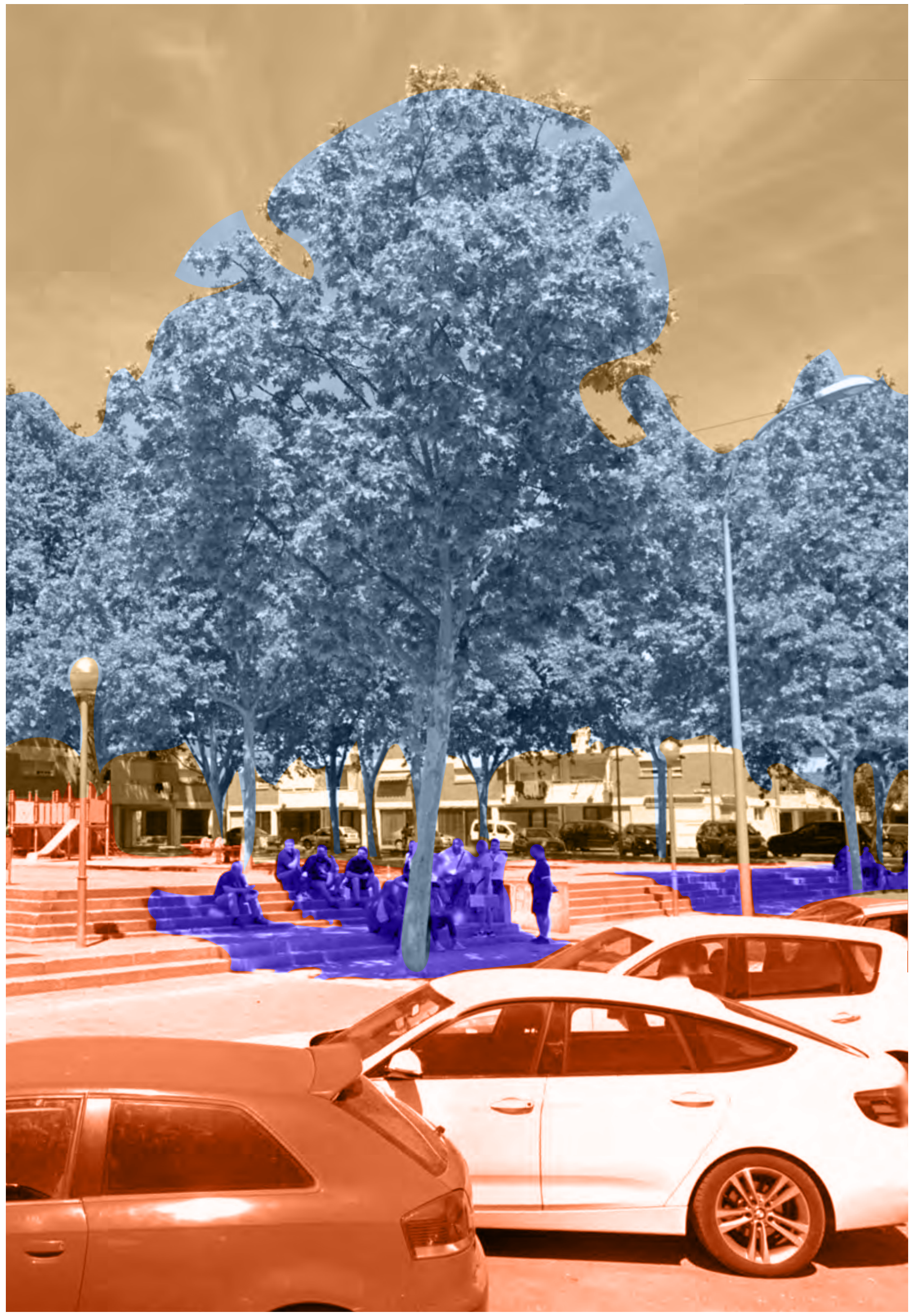


Figure 1.2: A group gathered under three shades in a square in la Mariola. (Google View)

et al. 2020), the placement of meteorological stations[2], and the effectiveness of interventions assigned[3] often fail to reflect the complex reality of urban populations.

The combination of phenomena in urban areas builds on the system's vulnerability, with catastrophic consequences for inhabitants and ecosystems. Urban areas amplify these challenges through the Urban Heat Island [UHI] effect, a phenomenon first documented by Luke Howard in 1833. UHI refers to the increased temperatures in urban areas compared to their rural surroundings (Oke 1982; Gunawardena et al. 2017; García 2022), driven by urban forms and materials that absorb and retain heat (Gunawardena et al. 2017; García 2022). This temperature differential ranges from 1–7°C during the day and 2–5°C at night (US EPA 2014; Keith & Meerow 2022), which means that urban temperatures continue increasing due to the materiality with what cities are built, such as asphalt, ceramic, and concrete, emits heat at night and hinders the nocturnal cooling (Gunawardena et al. 2017; Keith & Meerow 2022). The loss of natural ecosystems, waste heat emissions, and limited nocturnal cooling exacerbate this issue (ibid). (See Figures 1.2 and 1.3).

In certain contexts, such as arid and semi-arid regions, urban forms like irrigated parks and gardens can create localised cooling effects, forming "cooling islands" that contrast with surrounding heat (Shashua-Bar et al. 2010; Wheeler et al. 2019; Keith & Meerow 2022; Liu et al. 2024). These observations underscore the importance of context-specific research and solutions, particularly in Mediterranean regions prone to extreme heat, to continue exploring the complexities of these phenomena.

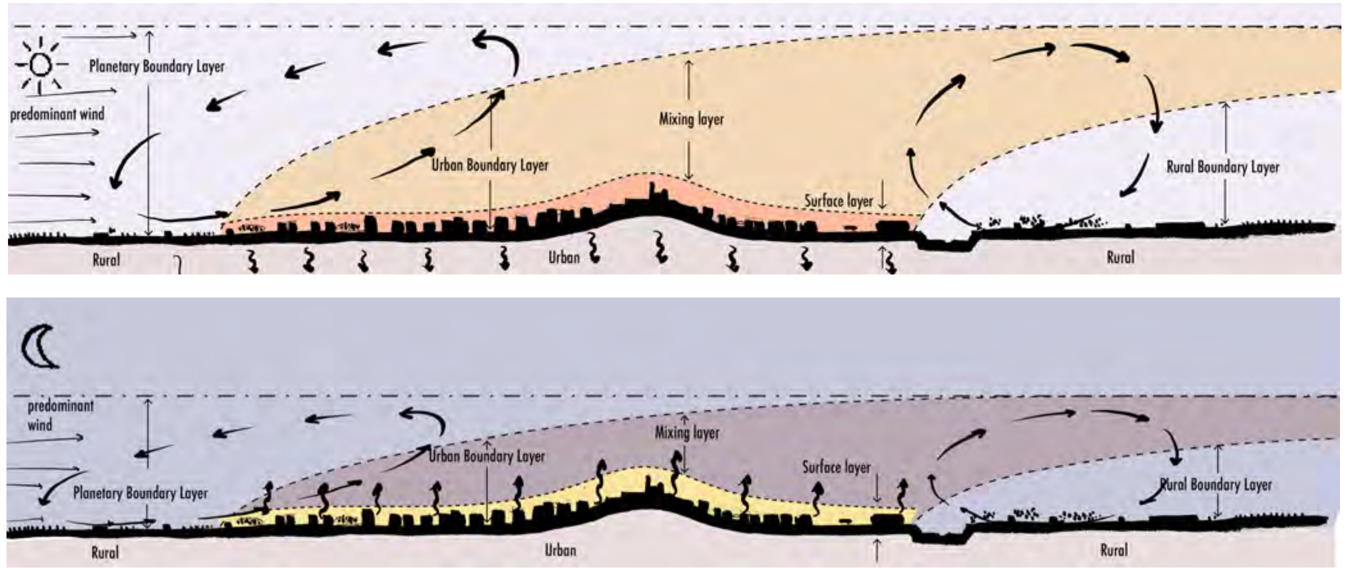


Figure 1.3: Hypothetical representation of urban energy balance on a schematic section of Lleida, based on Gunawardena et al. (2017).

2 I solicited data from the meteorological station, the Meteocat, since it was not available online. I received data from four with varied locations and periods of activity. The closest working one is located 3km south of the urban area (Meteocat 2023). (See Appendix A: Meteorological Station in Lleida for more info about the varied stations' locations).

3 The protocols' lines of action range from warning the population to remember to take actions to avoid extreme heat, such as drinking water regularly, using a hat, walking in the shade, or avoiding being outside in the peak of the heat Field (Departament d'Interior 2023). Also, 'climatic shelters' become accessible climatised spaces. However, they are a quick fix without a well-planned network strategy.

1.3 CASE STUDY: LLEIDA. CLIMATE CHALLENGES ASSOCIATED WITH THE CONTEXT SPECIFICS.

This research uses Lleida, a medium-sized city in Catalonia, Spain, as a case study (See Figures 1.5 to 1.8 to read the city and its surroundings). With a population of 142,990 (Idescat 2023) and a semi-arid continental climate, Lleida experiences recurring extreme heat stress. As the author's hometown, Lleida provides a unique opportunity to explore heat mitigation strategies through the lens of landscape architecture and urban-rural dynamics due to its particularities and the acceptance that exploring this unprecedented field can yield for the city.

Medium-sized cities like Lleida (UCLG n.d.) face particular challenges in addressing heat stress. Budget constraints often lead to the adoption of generic solutions that lack contextual specificity or continuity, sometimes resulting in superficial greenwashing efforts. To counter this, resilience planning thinking emphasises the importance of long-term, adaptable strategies that build on local conditions while preparing for uncertainties.

Lleida's compact urban form also protects its surrounding rural area, known as l'horta (orchard). This area constitutes 75% of the municipality and supports diverse agricultural activities (Aldomà Buixadé 2012). However, this agrarian landscape is increasingly vulnerable to water stress and ecosystem degradation, further complicating the urban-rural relationship in the context of heat resilience. These characteristics make Lleida a compelling case for examining how landscape planning can integrate heat mitigation with ecological restoration in Mediterranean xeric landscapes. Moreover, an actualised plan is currently manifestly lacking for the city, and there is no interest in analysing the consequences of this absence; this work aims to use this opportunity to claim the need to introduce innovative strategies at the planning level.

"The original natural ecosystems of the territory have been degraded or disappeared; (and) extensions of primitive forest have been substituted either for farmland, either Mediterranean pine forest that in natural conditions are restricted to little extension or even varied pattern of vegetal communities" (Observatori del Paisatge 2010:50).

This landscape transformation raises crucial questions about the role of agriculture extensions and the restoration of novel ecosystems in the context of urban resilience and heat mitigation: What happens when the original ecosystems have disappeared? How should novel ecosystems be restored?

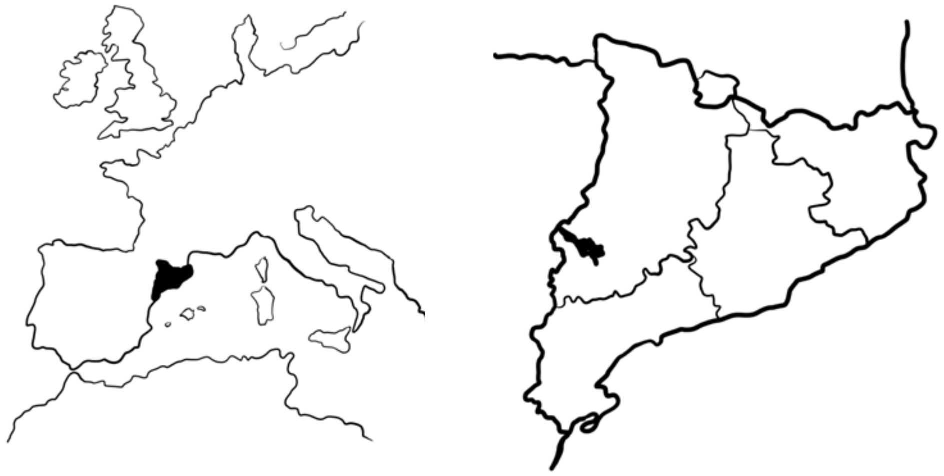


Figure 1.5: Situation map. Catalonia in Relation to the southern part of Europe and the municipality of Lleida in Lleida's municipality limits the situation concerning Europe and Catalonia. The Catalan map includes habitat classification, and the red area represents agriculture. (Geoveg 2018).

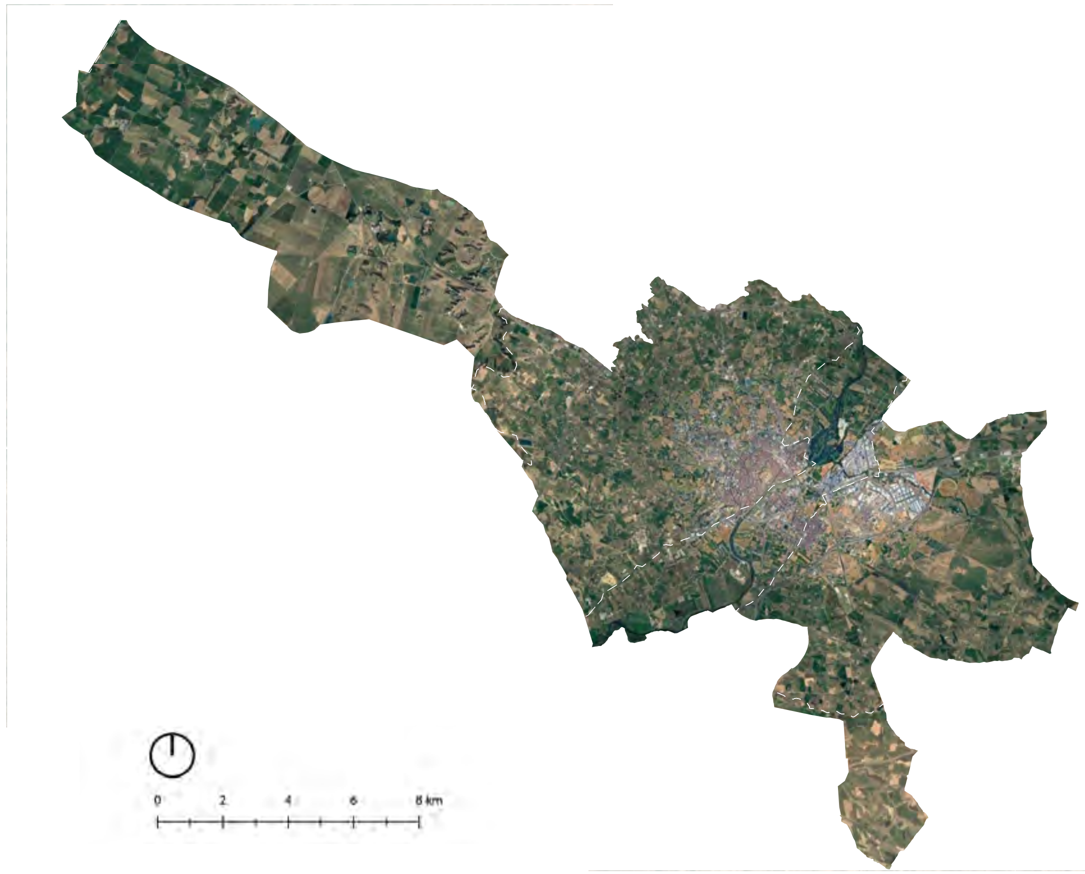


Figure 1.6: Orthophoto of Lleida's municipal limits, including the annexed region of Raïmat.

Figure 1.7: Map of Lleida municipality with surrounding settlements.

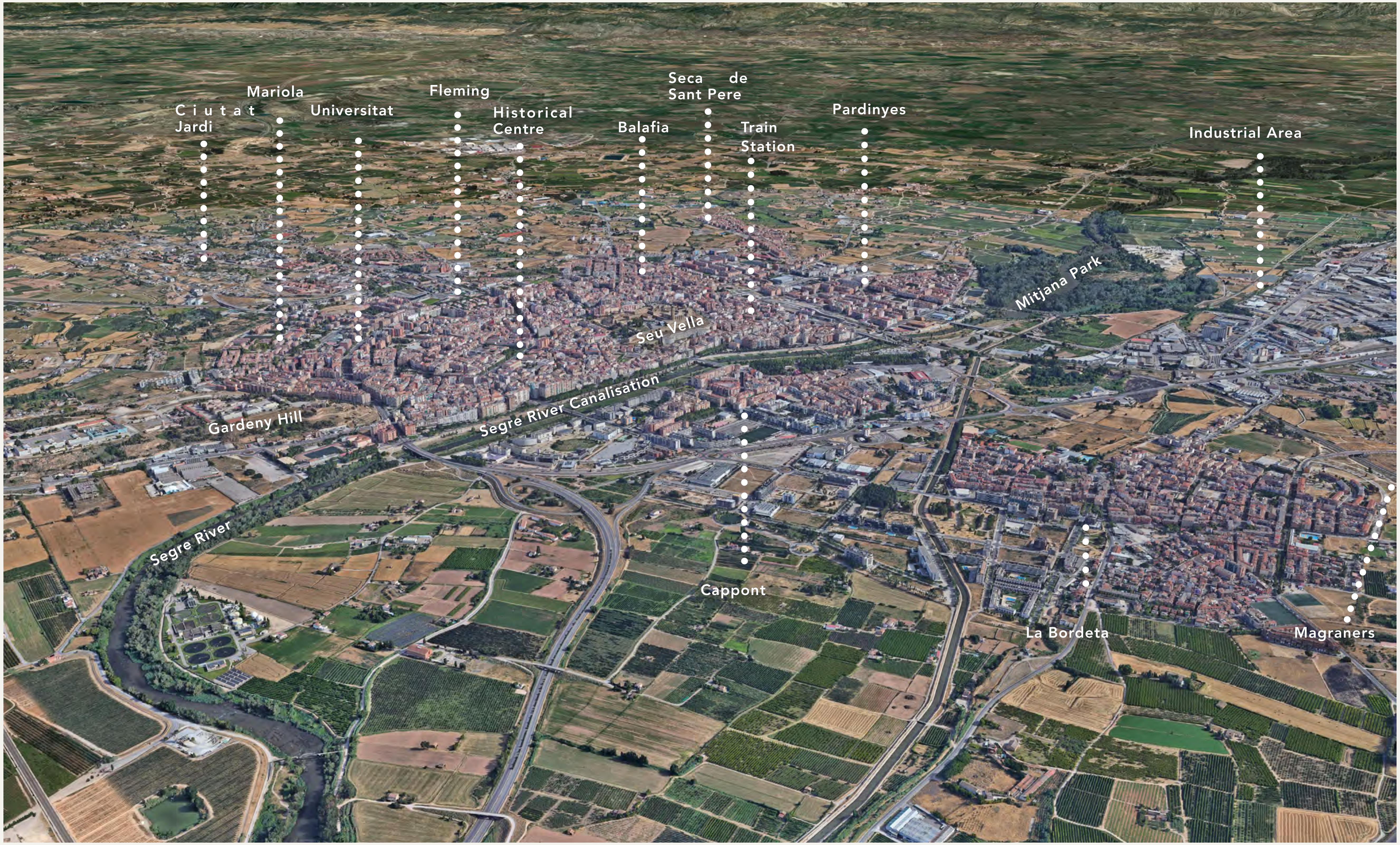


Figure 1.8: Axonometric view of the urban area, with neighbourhoods and the closer surroundings. View from the south, or marked on Figure 1.7.

1.4 IDENTIFYING THE PROBLEM: IS IT POSSIBLE TO INTEGRATE HEAT MITIGATION WITH RESILIENCE AND ECOLOGICAL RESTORATION IN URBAN ENVIRONMENTS?

Despite the urgency of mitigating urban heat, current approaches often fail to integrate heat mitigation, urban resilience, and ecological rehabilitation into a cohesive framework (Figure 1.9). Nature-based Solutions [NbS] have emerged as a prominent urban resilience and heat mitigation strategy. Research highlights the cooling effects of greenery in cities, such as trees and vegetation, which significantly reduce the Urban Heat Island [UHI] effect and enhance human well-being (Gunawardena et al. 2017; Imran et al. 2019; Balany et al. 2020; Lehmann 2021; Iungman et al. 2023). Moreover, the number of studies emphasising the benefits of green infrastructure [GI] as a heat mitigation strategy has grown considerably in recent years (Meerow & Newell 2017; Balany et al. 2020). Reintroducing greenery—such as urban forests, green roofs, or vegetated corridors—is seen as a promising strategy for cooling cities and improving their microclimates. However, implementing these solutions often remains partial, disconnected, or poorly contextualised. NbS initiatives are frequently criticised for their 'utilitarian framing' (Waylen et al. 2022), prioritising societal needs over ecological integrity. As isolated initiatives (Lehmann 2021), they can adapt to space and budget availability. Nevertheless, they can create disservices and perpetuate injustices (Lyytimäki 2015; Anguelovski & Corbera 2023) due to their immediate responses and neglect of the system as a whole.

In contrast, restorative strategies prioritise ecosystems' health, resilience, and functionality while 'conserving biodiversity and improving human health' (Gann et al. 2019:6). These approaches emphasise ecological integrity over short-term utility, focusing on place-based solutions that are inclusive and reflective of local contexts. Yet, pathways beyond conventional NbS applications are limited, leaving a significant gap in guiding urban greenery initiatives with their climate regulatory capacities. This gap underscores the need for a holistic approach integrating urban heat mitigation, resilience, and ecological restoration. Furthermore, any restorative action necessitates a definition of the referent ecosystem. According to Klaus and Kiehl (2021), 'rehabilitation' would be a more accurate concept for novel ecosystems. This represents an opportunity for cities to increase resilience and mitigate heat impacts effectively by increasing the presence of healthy ecosystems. However, there may be contradictions between the critical role of specific ecosystems as biodiversity hotspots and their function in assisting with heat mitigation, such as other than forest-type habitats' role in heat stress. Such an approach must go beyond adding greenery to cities and instead aim for systemic transformations that restore ecological balance, reduce socio-spatial inequities, and build long-term resilience.

1.5 RESEARCH FOCUS: KEY QUESTIONS AND OBJECTIVES

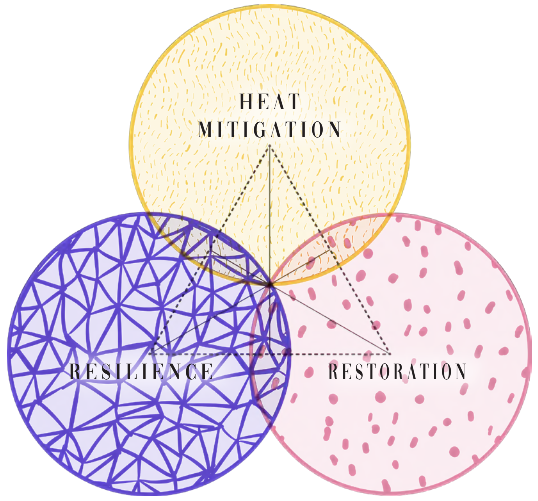
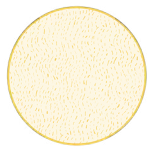
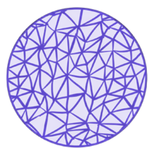


Figure 1.9: Conceptual diagram depicting three topics.

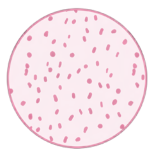
This research aims to develop a symbiotic strategy that integrates heat mitigation, resilience improvement, and ecological rehabilitation through the proposed concept of a rehabilitative heat-resilient green-blue infrastructure [HRGBI]. The central hypothesis is that HRGBI, adapted to Lleida's local context, can benefit humans, other-than-humans, and shared urban environments. The research addresses the following key questions:



- *How do urban form, land use, and ecological degradation contribute to heat stress in Mediterranean cities, and what role can landscape planning and design play in mitigating these impacts?*



- *What specific urban planning and design parameters enhance heat resilience in Mediterranean cities?*



- *What strategies can urban landscape planning use to integrate ecological restoration and heat mitigation, particularly in Mediterranean xeric landscapes like Lleida?*

1.6 DEFINING THE RESEARCH SCOPE AND METHODOLOGICAL FRAMEWORK

This research combines theory, case study analysis, and practical proposals to contribute to the evolving discourse on heat resilience and ecological restoration from a landscape planning and design perspective. Through an explorative approach, its final goal is to create a Leitbild that integrates a 'call for action' (Potschin et al. 2010) for Lleida while identifying aspects that can be extrapolated to other situations, enhancing this study's replicability.

The research is limited by the case study of Lleida, which focuses on its specific environmental, climatic, and urban-rural characteristics. The analysis and proposal are structured across three spatial scales: territorial, urban-rural, and local (See Figure 1.10).

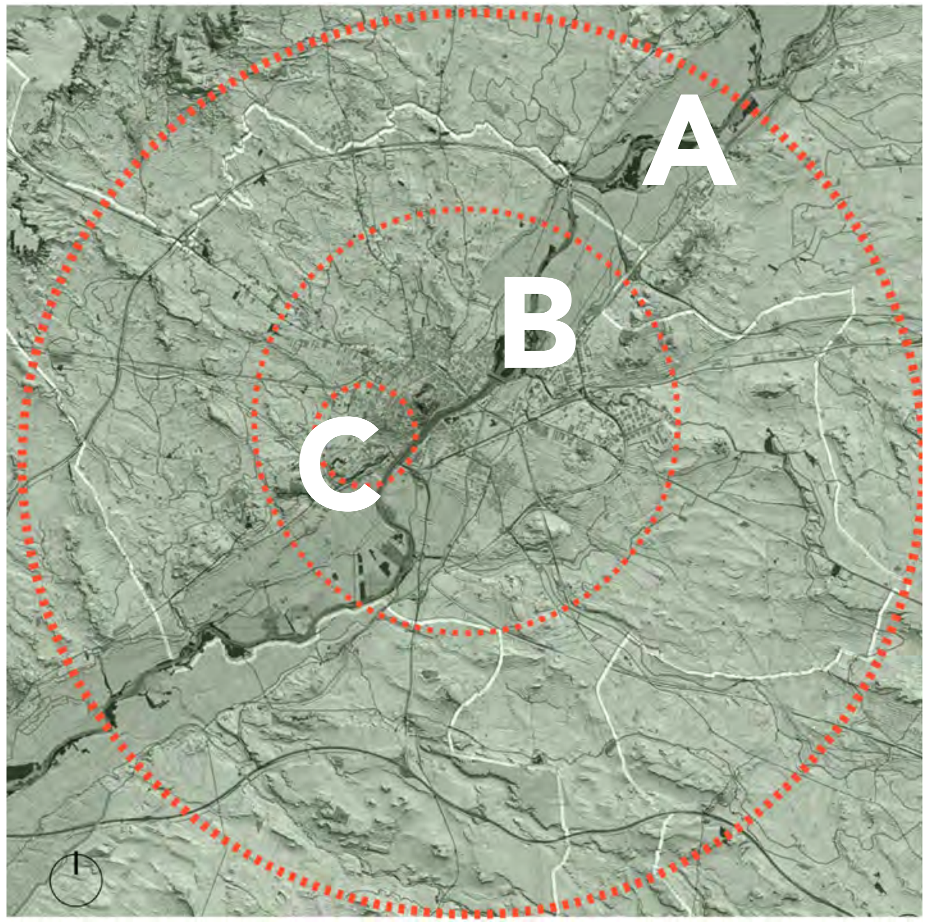


Figure 1.10: Framework with focus area on the Lleida map.

A - Territorial:
This level encompasses a multi-municipality level, offering a broad view of ecosystems, habitats, and protections to assess regional impacts on urban heat.

B - Urban-Rural:
This level focuses on the urban area and nearby regions impacted by the UHI effect. It will examine the relationship between rural and urban areas using exploration and urban green space distribution analysis.

C - Localised Urban:
At this level, the research focuses on a specific area identified as a priority. This framework involves detailed examinations of urban heat impacts and the role of green spaces, guiding targeted mitigation efforts under the proposal phase. This work further exposes the definition of this area's priority.

1.7 STRUCTURE FOR NAVIGATE THE THESIS

As the title suggests, this work embodies a highly explorative and critical approach to the topics and the case study that enriched and complicated the research process. Initial findings developed into the foundational research component, which consistently evolved. To improve the reader's understanding, the resulting work follows a structure aligned with the research design, incorporating a foundational theory, context analysis, and experimental testing organised across eight stages of chapters:

Chapter 1: Introduction. Outlines the background, context, motivations, and aims of the research.

Chapter 2: Material and Methodology. Provides a comprehensive overview of the methods and resources used.

Chapter 3: Foundational Research explores relevant research and theories on urban heat complexities and mitigation strategies and sets the tone for approaching resilience and restoration and the basis to answer the research questions.

Chapter 4: Rehabilitative HRGBI. This chapter purposefully revises the conclusion of the previous chapter. It defines and characterises the concept of rehabilitative HRGBI for the study.

Chapter 5: Analytical Research: Existing State. This chapter examines Lleida's environmental, climatic, and urban-rural characteristics through secondary data. The case study follows the factors summarised by Keith and Meerow (2022) as the primary influences on the effects of the UHI.

Chapter 6: Analytical Research: Potentialities. This chapter identifies vulnerabilities through a heat map study, delves into the characterisation of the cooling islands, and generates first-hand data to define the potential to make Lleida more heat resilient, looking to potential heat resilient habitats.

Chapter 7: Exploratory implementation. This chapter tests what implementing a Rehabilitative HRGBI in Lleida would imply from a landscape planning and design perspective. Critically analysing the outcomes and limitations generates conclusions for further research.

Chapter 8: Discussion. The concluding words summarise the research findings, critically assess the implications of this work, and present the recommendations for further research.

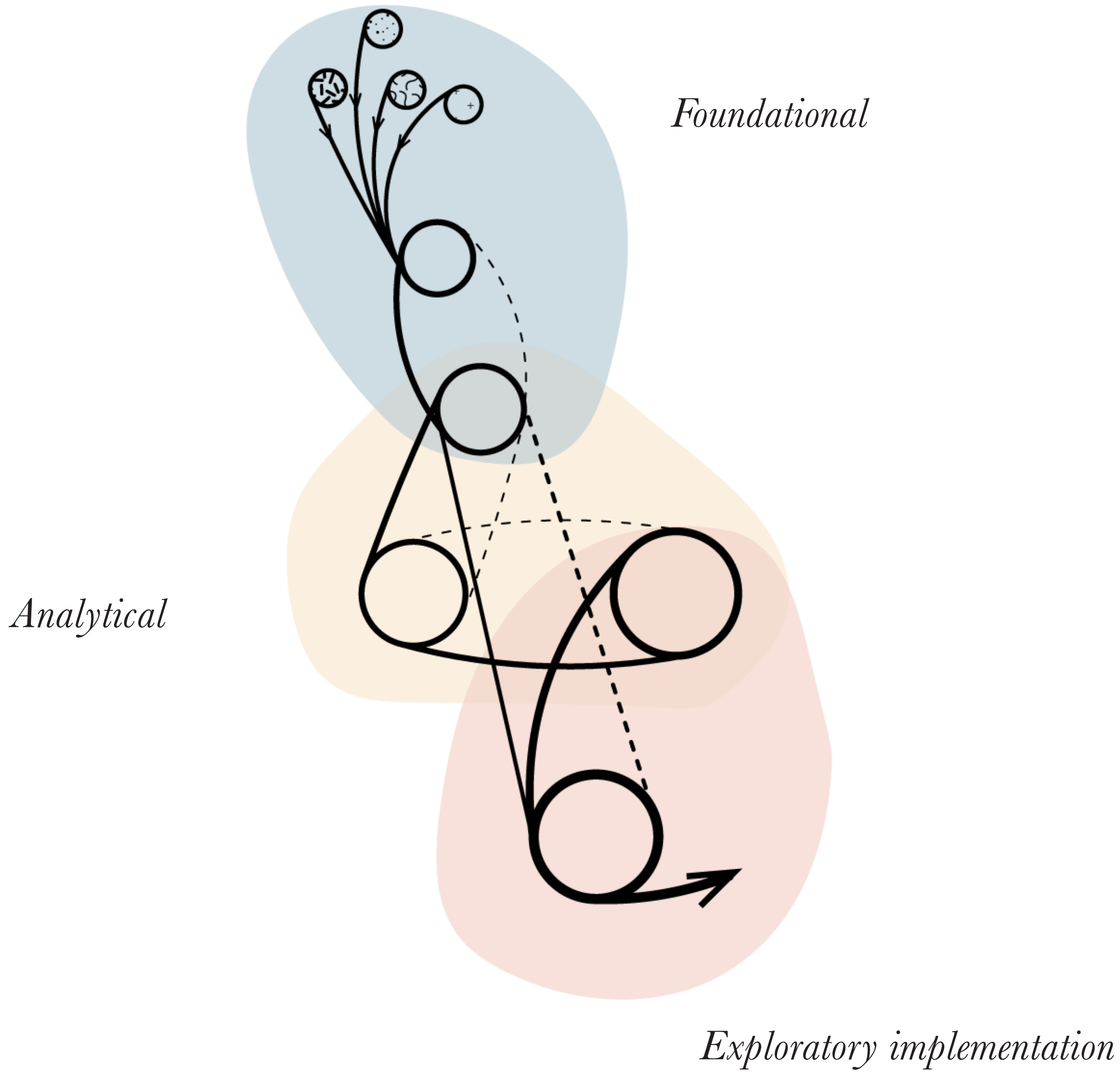


Figure 2.1: Illustration of the process including the three sections of the study – Foundational, Analytical and Exploratory implementations.

CHAPTER

2

UNVEILING THE TOOLS: NAVIGATING MATERIALS AND METHODOLOGIES

This chapter outlines the research process and methodology for merging multiple data in three to four phases: Foundational, Analytical of the existing, Analytical of potentialities, and Exploratory implementation (See Figure 2.1). The second section expands on this work's combined data collection and analysis methods under the four phases.

2.1 MAPPING THE BLUEPRINT: STRUCTURING THE RESEARCH DESIGN.

This study adopts an exploratory case study approach, a research strategy suited to framing and investigating the complexities of contemporary phenomena (Biggam 2008). The intersection of three interconnected issues—heat stress, resilience, and ecological restoration—creates a multifaceted phenomenon that has not yet been extensively studied as a unified subject. Using Lleida as a case study to address this complexity provides contextual insights while generating broader questions relevant to climate adaptation research. The research examines Lleida's urban form and its relationship with surrounding landscapes, land use patterns, and agricultural practices through the lens of these three themes. This enriches the study with its particularities, guiding the implementation strategy from a landscape planning and design perspective.

The research follows an iterative process based on grounded theory methodology (Bryman 2012). While this approach initially introduced chaos, the study remained structured, progressing from an initial contextual understanding to testing literature-based solutions against the case study's realities following the path illustrated in Figure 2.2. By maintaining an exploratory stance, the study continuously refined its methodology and analytical approach according to the needs of previous findings while opening more questions that could only be answered with other literature reviews, as was the case of the Mediterranean habitat characterisation study. This process offered an interesting understanding of the more suitable methods to approach these questions. For instance, the Friendly Afforestation Guideline (European Commission 2023) was examined for implementation

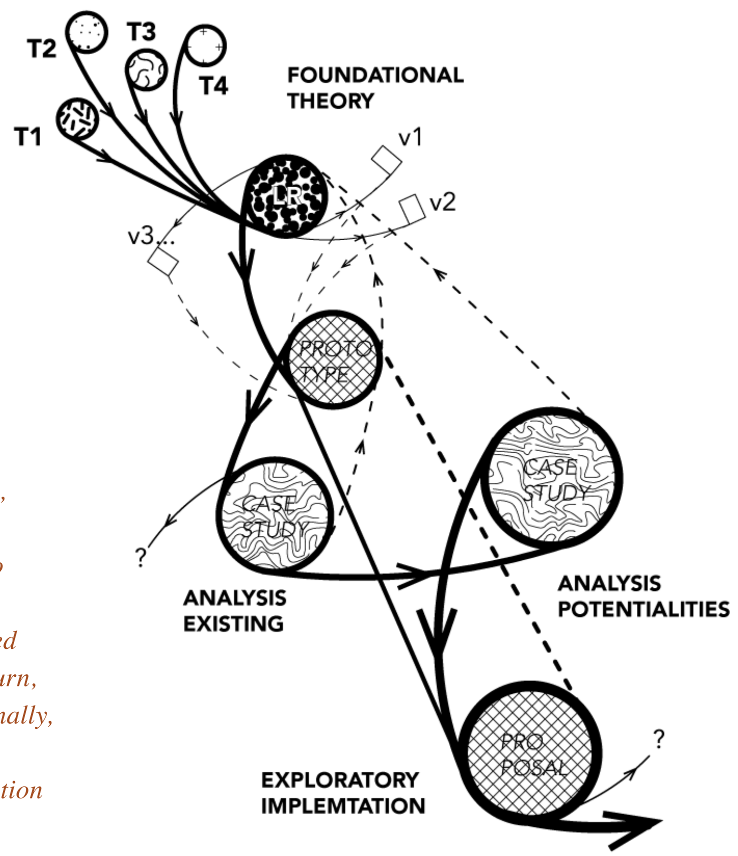


Figure 2.2: An overview of the research process diagram. Illustrate how the three initial main topics (urban heat stress, resilience, and ecological restoration) expand to four by incorporating 'implementation' as part of the research -T1 to T4- and generate a series of variables -v1 to v3- through the literature review. Thanks to the iterative process loop required by grounded theory research, it creates a prototype that, in turn, guides the analysis part and is revised through this study. Finally, the exploratory implementation section generates a proposal that generates new questions and can modify the implementation prototype.

strategies. However, it suggests that identifying the area and reference habitats is the initial step for any afforestation or reforestation process. Consequently, a new body of literature on habitat characterisation was included.

The graphic documents also reflect an explorative attitude throughout the variability of styles. Although the aim was to follow a graphic narrative, exploring the best representation drove the graphical results.

2.1.1 A Dynamic Four-Phase Research Framework

The research design was non-linear. However, it is presented and organised around four phases, each with particular objectives, primary methods utilised, and outcomes. Table 2.1 expands on this.

Table 2.1: Research phases.

Research phases	Objectives	Primary method	Outcomes
Foundational (Ch.3)	Delve into the current topic discussions from an academic and real-life practice.	**Literature Review** (Academic and governamental documents)	Principles for a Rehabilitative HRGBI. (Ch.4)
Analytical – Existing situation (Ch.5)	Recognise Lleida existing situation in terms of heat stress, resilience capacity and ecological protection.	**Governamental document** review and **GIS**	Critical review of its weakness.
Analytical – Potentialities (Ch.6)	According to the principles of multiaction, heat vulnerabilities and existing cooling islands are analysed from a land use and ecosystem service approach.	**GIS, Exploration**s and **ESTER 2.0**.	Heat stress, land use, agricultural practices and ecosystems overlap to answer the research questions 1 and 2.
Exploratory implementation (Ch.7)	Testing the possibilitiy of integrating cooling islands in the urban environment with distances around the 300m and surfaces over 200sqm.	**GIS** and **literature review**.	An implementation toolkit according to existing situation, responding research question 3.

2.2 RESEARCH METHODS: INTEGRATING DATA COLLECTION AND ANALYSIS

This study employs a mixed-method approach, integrating data collection and analysis techniques to test and refine the theoretical framework through a deductive process (Bryman 2012). The iterative nature of grounded theory (Grounded Theory Explained in Simple Terms 2021) enables hypothesis definition, theory revision, and methodological adjustments throughout.

The data collection process was a bit unorganised, which, according to Bryman (2012), is naturally a part of the process. It combined primary and secondary sources (Hox & Boeije 2005) and was categorised into three branches: **literature review, geographical information,** and **local knowledge**. An overview of these branches and the material composing them is represented in Figure 2.3.

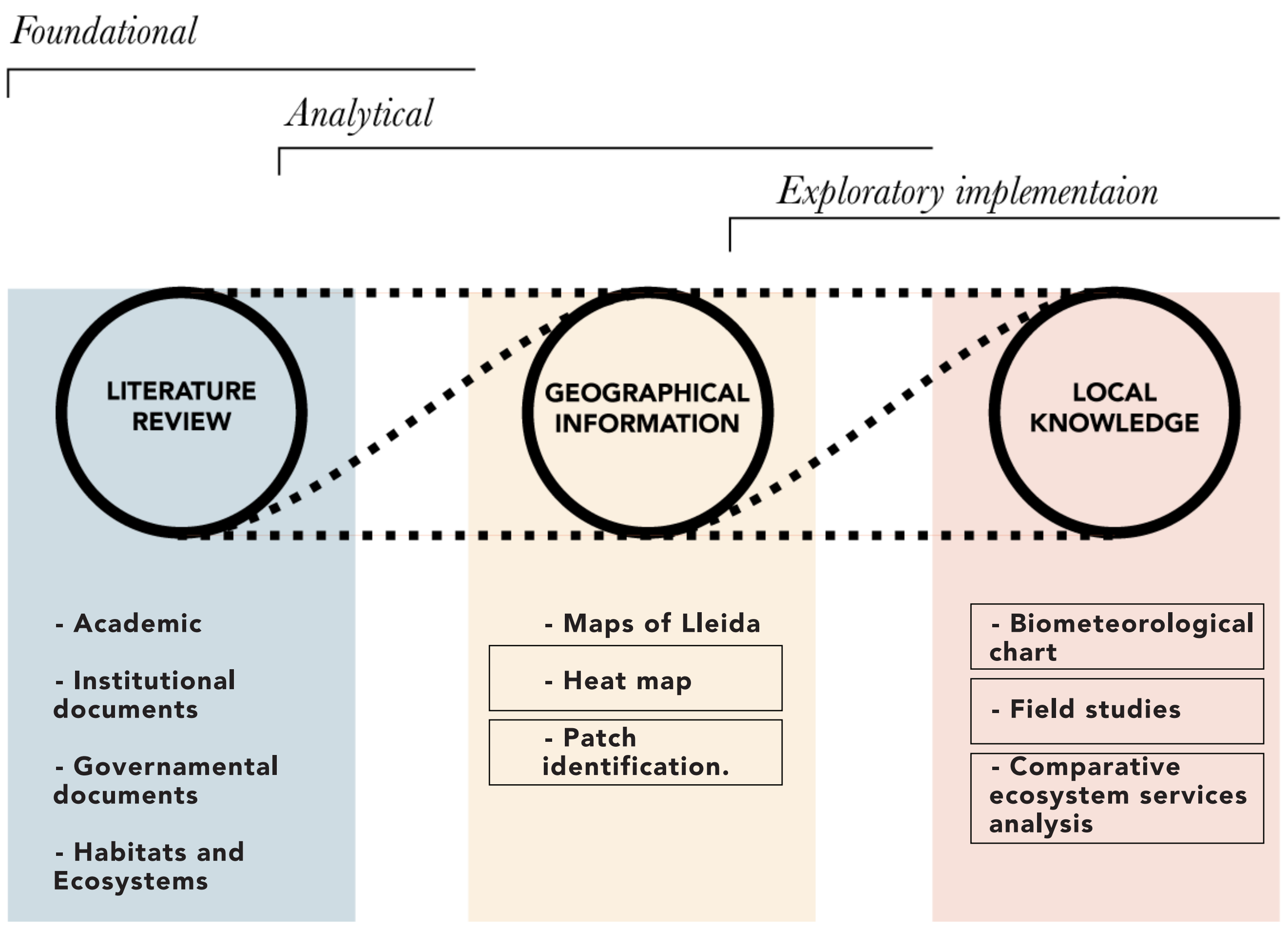


Figure 2.3: Diagram of the data collection overview, encompassing the types and methods utilised in each section. Each section is approached from the perspective of the three threads, enriching the concepts of heat complexities, resilience, and ecological restoration. Framed are the first-hand data.

2.2.1 *Theoretical Foundations: Building Knowledge Through Literature Review*

The literature review method is at the core of this study since it helped delve into the actual state of the question. The revised material included **academic text, institutional documents** and **governmental documents.** The attitude has constantly tried to be critical, identifying what is excluded and looking for papers that support different views. Similarly, a critical discourse analysis approach was considered when approaching governmental plans, policies, projects, and strategies: observing what is excluded, identifying who or what is the main subject, which qualifiers are used, and identifying the nodal points of the discourse (Jørgensen & Phillips 2002) helped to keep a critical eye.

Academic and Institutional Literature: Identifying Key Concepts.

The academic text's information sources included Google Scholar, Science Direct, and Scopus, which were the primary search platforms for identifying the most relevant literature on heat stress, urban heat mitigation, heat resilience, urban resilience, and urban ecological restoration. Institutional documents from the European Commission, including policies for implementation, were also considered.

Jack Ahern's urban resilience principles (Ahern, 2011) were instrumental in shaping this framework, while the Biodiversity-Friendly Restoration Guidelines (European Commission, 2023) informed the restoration methods.

The heat mitigation study became the most extensive investigation into the critical variables considered in each study. It prioritised studies that generated first-hand data and complemented others that examined the multiple scales of heat stress to extract strategies to mitigate urban heat stress and their critical variables to be considered in the contextual analysis. Ultimately, the studies were grouped into three categories according to their scale of influence.

- **Performance of individual features** (e.g., trees, shrubs, and cooling distribution).
- **Systems-level entities** (e.g., park size and shape).
- **Network-level strategies** (e.g., planning of green-blue infrastructure [GBI]).

The primary outcome from the foundational part defined the design principles of the object of this study: the Rehabilitative Heat-Resilient Green-Blue Infrastructure. Emulating a hypothesis, they are later tested in the case study under the Explorative Implementation part.

Governmental Documents: Policy and Planning Analysis

The scale of this research focuses on the municipality of Lleida. Still, the data source was municipal or regional from the Catalan Government, Generalitat, or supportive entities, such as the Landscape Observation agent. These documents provided a view of the existing situation regarding planning, protections, policies, and documents dealing with climate challenges. At a municipal scale, the data analysed is presented in Table 2.2.

Table 2.2: Revised municipal documents

Abbreviation	Document - Catalan	Document - English	Author (year)
[GP99]	*Pla General de Lleida. Mu-nicipal d'Ordenació Urbana i Territorial 1995-2015. Normes urbanístiques (Planejament refós gener 2022)*	General Plan of Lleida. Municipal Urban and Terri-torial Planning 1995-2015. Urban planning rules (Re-vised planning January 2022)	Ajuntament de Lleida (2022a)
[GP18]	*Pla d'Ordenació Urbanísti-ca Municipal de l'Ajunta-ment de Lleida | Document Aprovació Inicial*	Municipal Planning Plan of the Lleida City Council I Initial Approval Document	Ajuntament de Lleida (2018)
	Declaracio d'Emergencia Climatica	Declaration of Climatic Emergency	Ajuntament de Lleida (2022b)
[PCCL19]	*Pla Canvi Climàtic, Lleida 2030*	Plan of Climate Change of Lleida 2030	Ajuntament de Lleida (2019)
	Document de treball: Pla del Verd de Lleida	Working document: Plan of the Green of Lleida	Ajuntament de Lleida (2022c)
[POCSMLL]	*Pla d'actuacions per pre-venir els efectes d'una on-ada de calor sobre la salut al municipi de Lleida*	Action plan to prevent the effects of a heat wave on health in the municipality of Llevida	Ajuntament de Lleida (2023)

Habitat and Ecosystem Studies: Understanding Environmental Context

At the Catalan level, there exists bast work on habitat definition, characterisation, and assimilation to CORINE biotopes and, later on, EUNIS terminology (Generalitat de Catalunya 2017a). They are sampled in the Catalogue of Catalan Habitats document (Generalitat de Catalunya 2017b) and divided into volumes based on the habitats. The information here is entirely dispersed; it describes the habitats but does not identify which ones are in a specific region. The two climatic regions corresponding to Lleida are the Mediterranean Continental and Sicoric Territory. Parallel to this classification, the Habitats of Communitarian Interest [HIC] also describes the habitats, but this information also includes geographical information. Finally, the last group of classifications is the Map of the Potential Vegetation in Catalonia, which makes a potential distribution of the original disappeared ecosystems (Carrillo et al. 2019). However, it does not consider the territory's

Table 2.3: Reference list for habitats according to their classification.

Reference	Title	Author /Year	Comment	Reference classification
HIC	*Volum I Introducció*	Vigo et al.(2005)	Introduction to the Cataln habitats of Communitarian Interset	CORINE biotopes
HIC	*Volum IV 3 Vegetació arbustiva i herbàcia (Vegetació arbustiva)*	Vigo et al. (2006)	Catalan bushes	CORINE biotopes
HIC	*Volum VI 4 Boscos.*	Carreras et al. (2015)	Catalan Forest	CORINE biotopes
HIC	*Volum IV. Vegetació arbustiva i herbàcia*	Aymerich et al. (2016)	Bushes and grasses volume from the Manul of Catalan Habitats.	CORINE biotopes
HIC	*Volum V 3 Vegetació arbustiva i herbàcia (Prats i pastures*	Carreras et al. (2016)	Catalan Meadows	CORINE biotopes
	Correspondència entre els tipus d'hàbitats d'interès comunitari, els hàbitats CORINE de Catalunya i la classificació EUNIS.	Generalitat de Catalunya (2017a)	Table with Habitat of Communitarian, CORINE and EUNIS (outdated classification)	CORINE - EUNIS (2017)
	List of Catalonia CORINE habitats	Generalitat de Catalunya (2017b)	List of codes and names	CORINE biotopes
MVC50	*Mapa de vegetació de Catalunya 1:50.000*	Carrillo et al. (2018)	Memory of the map with legend and classification.	sintaxonomic order (Bolos et al. 2005)
HIC	*Volum IIa 1 Ambients litorals i salins. Hàbitats terrestres.*	Ferré Codina et al. (2018)	Salt	CORINE biotopes
MVC250	*Map de la vegetacio potencial de Catalunya 1:250.000*	Carrillo et al. (2019)	GIS map with codes	
	EUNIS Habitat Classification: Expert system, characteristic species combinations and distribution maps of European habitats.	Chytrý et al. (2020)	Digital model by FloraVeg.eu	EUNIS Terrestrial Habitat Classification 2021.
	EUNIS -EUNIS habitat types hierarchical view - revised groups.	European Environment Agency (2021)		EUNIS Terrestrial Habitat Classification 2021.

geomorphological characteristics as described by the Landscape Units (2006) and Aldomà (2012). Table 2.3 shows these habitats, including their classification and source.

All this information required a step forward in this work, which was not finally taken. It informed a general classification of the habitats without defining the species of referent habitats.

2.2.2 *Geospatial Analysis: Mapping the Urban and Natural Landscape*

Geographical information systems (GIS) are powerful tools for **collecting, managing, analysing**, and **creating** primary data; in this case, the program used was QGIS. GIS-based analyses identified land use, green spaces, and urban heat patterns. Key datasets were sourced from Lleida's municipality[4], the Cartographic Institute of Catalonia [ICC], and the Territorial Department of Housing and Ecological Transition of the Catalan government website, as is represented in Table 2.4. Some of the received shapefiles were finally discarded due to their coding, as they lacked a legend or were overly complex. Table 2.4 lists the shapefiles with the source and description.

Table 2.4: List of GIS-analysed maps along with their primary sources.

At urban-rural level	**Data source**
Land use	ICC
Agriculture typology	Territorial Department
Environmental features	Territorial Department
Forest and tree cover	Territorial Department
Habitats of Communitarian Interest	ICC
Water structures	ICC
Geomorphology	ICC
At urban level	
Parks	Lleida Municipality
Urban green spaces	Lleida Municipality

Moreover, QGIS was also used to generate a **heat map** using Landsat-8 data from June 2022, which coincided with the last heat wave registered in Lleida[5] when I did this map . This data became the primary data for identifying vulnerabilities and cooling areas through land surface temperature [LST] mapping. The equations and calculations used to achieve this map can be found in *Appendix B: LST Calculation*. I followed the YouTube video "Calculating Land Surface Temperature Using Landsat 8 Imagery in ArcGIS" from The GIS Hub .

Lastly, GIS facilitated the generation of **first-hand data** during the exploratory implementation stage. A 300-metre grid assisted in identifying available space in urban areas, allowing for the distribution of square-round-shaped surfaces over 200 sqm, which formed the central part of the exploratory implementation analysis.

4 They were received from the Urbanism Department and the Ecological Transition Department of Lleida's Municipality, on 16 February 2023.

5 Severe heat waves between the 10th and 19th of June 2022, with air temperatures over 40ºC. However, it was no coincidence with the dates and satellite orbit, so the closest date the satellite orbited over the area was the 24th of June 2022, assigned with path 198 and rows 31. https://landsat.usgs.gov/landsat_acq

2.2.3 *Local Knowledge: Capturing Site-Specific Insights*

First-hand data was created to fill some of the gaps identified in the first study of the existing situation. These were related to identifying UHI in Lleida and determining heat stress, the connectivity and use of urban green spaces, and the possibility of systematically studying their composition quantitatively. I generated a **biometerological analysis, site explorations,** and **ecosystem services analysis**.

Biometeorological Analysis: Assessing Heat Stress in Lleida

Climatic data relevant to Lleida[6] was scattered and often incomplete. Consequently, on 9 May 2023, I requested meteorological data from MeteoCat for stations in Lleida and analysed it for patterns of heat stress. The weather data from public meteorological stations did not allow for a comparison between urban and rural areas or for a clear assessment of the UHI in Lleida, as all weather stations are currently located around the city. Therefore, the factors described by Keith and Meerow (2022) that trigger the UHI effect are used to structure the presentation of Lleida's characteristics and to guide the research on heat impact in Chapter 5.

Table 2.5: Physiological Equivalent Temperature [PET] for various grades of thermal sensation and physiological stress levels in humans (Basarin et al., 2020:8).

PET (°C)	Thermal Sensation	Psycolofical Stress Level
< 4,00	Very cold	Extreme cold stress
4,00	Cold	Strong cold stress
8,00	Cool	Moderate cold stress
13,00	Slightly cool	Slight cold stress
18,00	Comfortable	No thermal stress
23,00	Slightly warm	Slight heat stress
29,00	Warm	Moderate heat stress
35,00	Hot	Strong heat stress
> 41,00	Very hot	Extreme heat stress

Using the data from October 2017 to September 2018, a physiological equivalent temperature [PET] based on Basarin et al. (2020) was calculated. The Universal Thermal Climate Index [UTCI], proposed by the same author, would have been more accurate, but the lack of comprehensive data made this impossible. Still, Table 2.5 is showing the stress level graduation used for the created biometerological representation..

Exploratory Field Studies: Observations and Community Engagement.

Seven exploratory visits were conducted in March 2023. During that time, firsthand observations, photography, and spontaneous conversations were used to investigate connectivity, vegetation, and social dynamics in Lleida's public spaces. They were also

6 Stations of Lleida-La Femosa, Raïmat, Lleida-Pla de Lleida, and Lleida-La Bordeta. The last two closed in 2013 and 2018, respectively. Details about these stations are in Appendix 1: Meteoritical Station in Lleida.

employed to select areas for a more detailed analysis, examining their feature composition through the ES analysis, which is explained further in the next point.

The performative walks traversed the four cardinal outskirt landscapes using both feet and eyes to achieve as many urban green spaces and variabilities in the landscape as possible. Furthermore, it facilitated the identification of naturally occurring vegetation communities and their associated states of degradation. The objective guiding the length and route was to fulfil at least one of the objectives: go around -**round routes [rr]-, go through -trespassing routes [tr]-, or go high-sightseeing points [sp]**-. Table 2.6 lists the explorations and their characteristics, and Figure 2.3 maps the routes. Pictures taken under explorations can be found in *Appendix C: Explorations images*.

Surprisingly, improvised conversations also occurred during some explorations, providing valuable insights and viewpoints on the visited place. The general approach to the users became quite natural, and leisurely conversations just popped up. The summary of each conversation can be found in *Appendix D: Conversations*. They have not been directly used to shape the proposal but have been key in ensuring the need for round routes for leisure, exercise, dog walking, and refreshing, chill, private places to be close to nature.

Table 2.6: Exploration description with visited areas for detailed analysis and conversations encountered under.

Number	Tittle	Type	Description	Detailed analysis area	Conversations
Expl.01	From the city centre to the outskirts.	tr	Walking from the city centre to the new urban development in the northwest part of the city.	Joc de la Bola Square Navarra Street	
Expl.02	Turó Llarg.	sr	To find a high point on the basin.		
Expl.03	Gardeny's Hill and Vallcalent Park.	sp+ rr	Connectivity, uses, views, vegetation, and barriers.	North Gardeny Hill Rural Area Vallcalent	Ismael and Pere
Expl.04	Santa Cecilia Park and Seu Vella´s Hill.	sp+ rr	Connectivity, uses, vegetation, and views.	Santa Cecila Park-North Seu Vella Hill	Sam and Augusta
Expl.05	Abandoned urban development Torres Salses.	rr+sp	Connectivity, uses, and vegetation.		Tatiana
Expl.06	Mitjana Park and Segre River canalisation.	rr	Connectivity, uses, vegetation, and barriers. Experiencing the walking connectivity of la Mitjana with the city and other green areas was the goal of visiting this territorial park in the north of the town and how it is connected with the Segre River Park.	Segre River Canalisation Mitjana Park	

MATERIAL AND METHODOLOGY

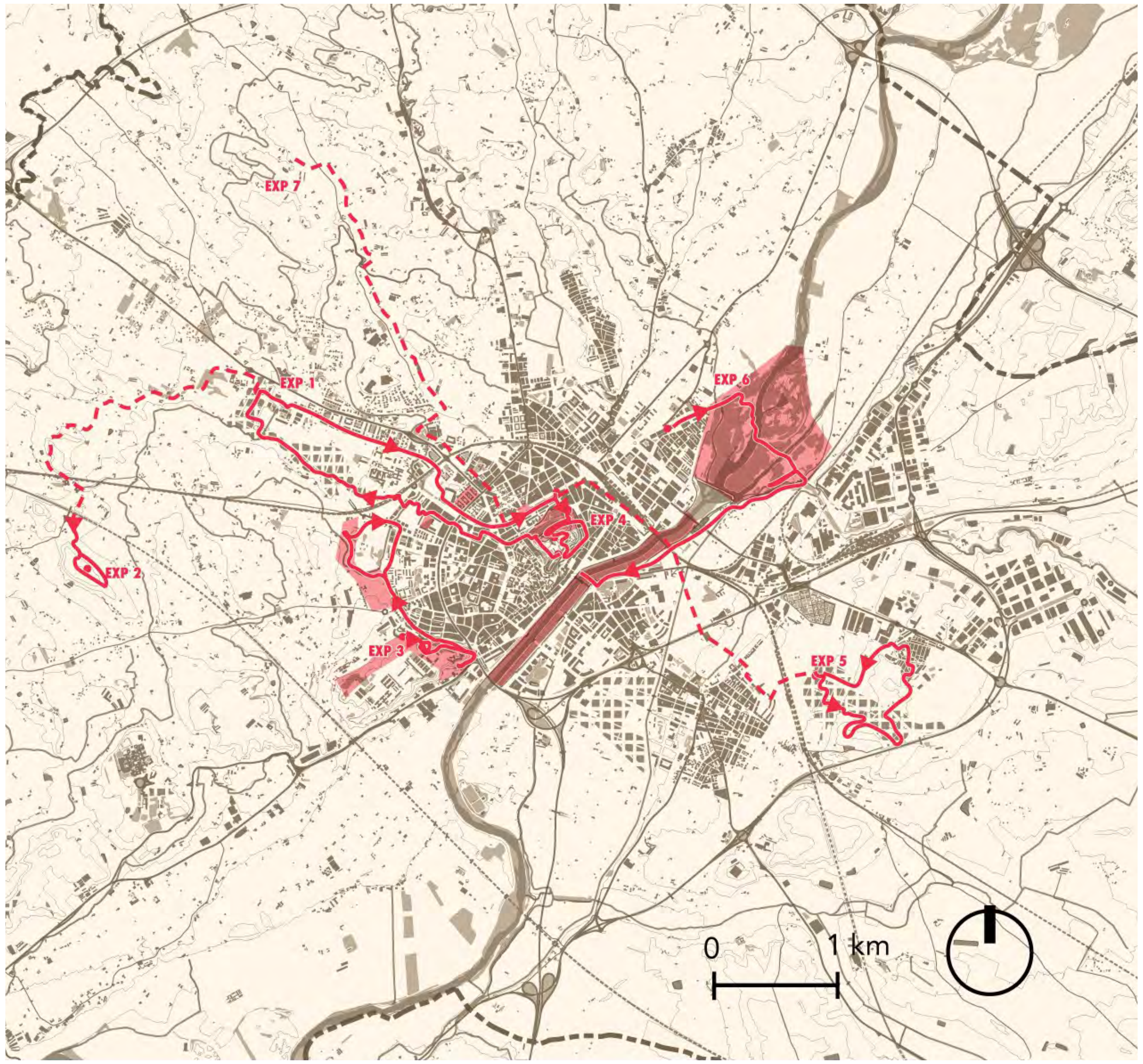


Figure 2.3: Lleida map with explorations.

Ecosystem Services Assessment: Evaluating Green Space Performance.

A detailed study of some spaces used **ESTER 2.0** (Boverket 2022) to evaluate the selected areas' ecosystem services [ES]. This tool offers a **quantitative approach to assessing ES**, addressing the challenge of integrating information across spatial and temporal scales (Haase et al. 2014:419). This work aimed to test it and evaluate its potential as a comparative analysis tool since I identified a gap in the studies that focused on the cooling potentialities of green spaces without considering their feature composition.

The tool was downloaded from the Boverket website, and the indicators were translated into English. While adapting this Excel tool to this analysis posed limitations, its application provided an opportunity to test its usefulness in generating actionable data for urban planning. The translated indicators used in ESTER 2.0 are listed in *Appendix E: Ecosystem Services and ESTER 2.0.*

Table 2.7: ES presented by Boverket (2022) and The Economics of Ecosystems and Biodiversity (2012) (TEEB – The Economics of Ecosystems and Biodiversity 2011; Boverket 2022b).

Ecosystem services category	Boverket (2022)	FAO and TEEB (2012)	
Supporting	Biodiversity	Maintenance of genetic diversity	Biodiversity
	Ecological interaction		Ecological interaction
	Habitats for especies	Habitats for especies	Habitats for especies
	Natural cycle		Natural cycle
	Soil formation		Soil formation
Regulating	Local climate		Local climate
	Erosion prevention	Erosion prevention and soil fertility	Erosion prevention
	Protection extreme events	Moderation extreme events	Protection extreme events
	Air cleaning	Improving air quality locally	Air cleaning
	Sound regulation		Sound regulation
	Regulation and cleaning of water flow	Regulaiton of water flow	Regulation and cleaning of water flow
	Pollinisation	Pollinisation	Pollinisation
	Biological control	Biological control	Biological control
		Carbon sequestretion	Carbon sequestretion
		Waste water treatment	Waste water treatment
Provisioning	Food	Food	Food
	Fresh water	Fresh water	Fresh water
	Raw materials	Raw materials	Raw materials
	Energi		Energi
		Medicinal resources	Medicinal resources
Cultural	Physical health	Recreation and physical health	Recreation and physical health
	Mental well-being		Mental well-being
	Experience and inspiration	Aesthetic apreciation	Aesthetic apreciation
	Social interaction		Social interaction
	Cultur heritage and identity	Tourism	Cultur heritage and identity
		Spiritual experience and sense of place	Spiritual experience and sense of place

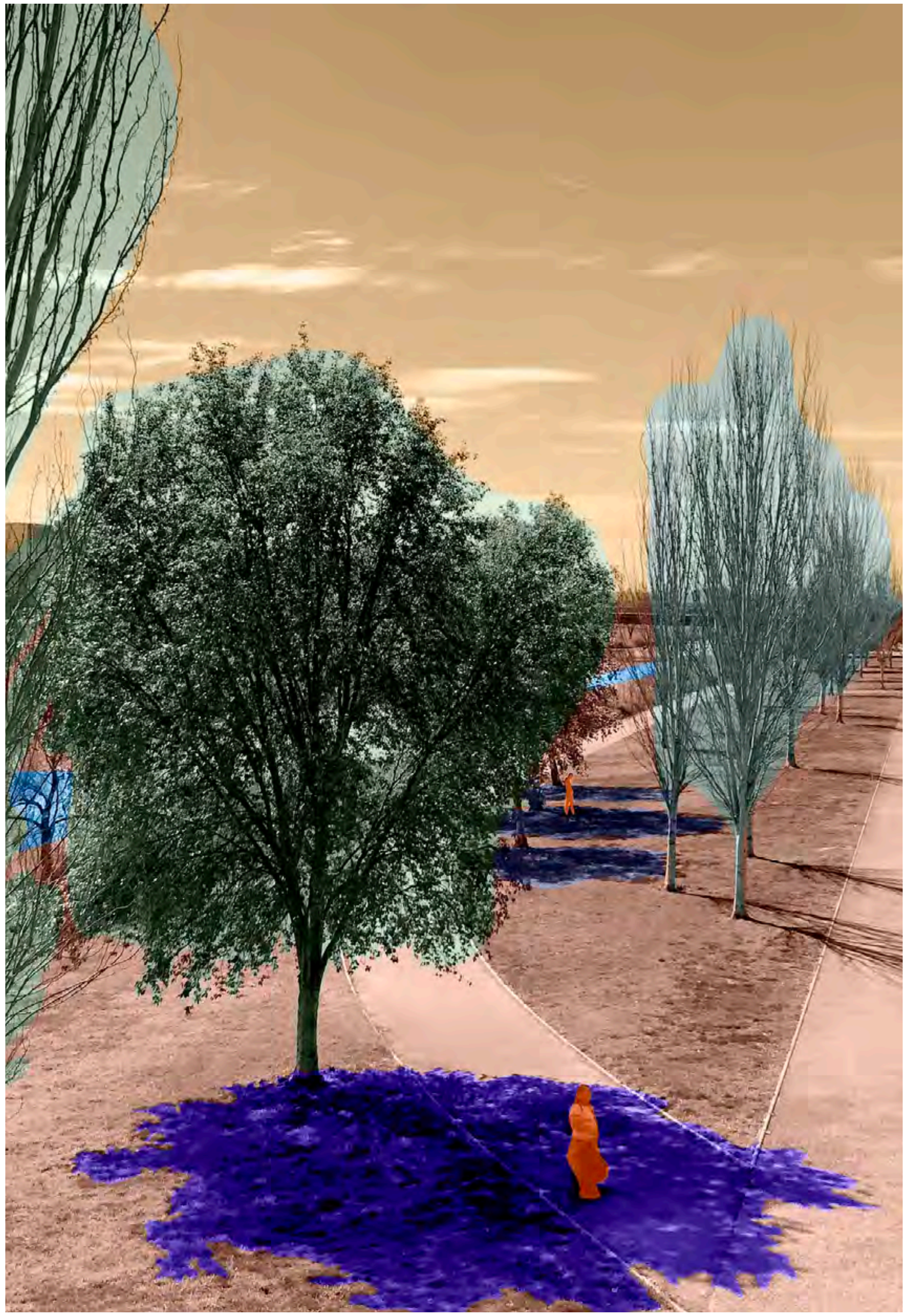


Figure 3.1: Person resting under the river three shading in March 2023. It shows the importance of evergreen trees in open areas.

CHAPTER

3

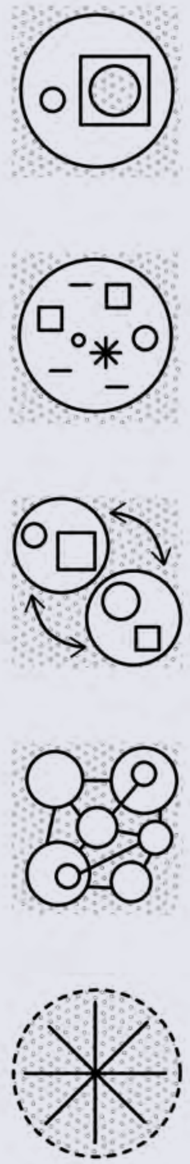
THEORETICAL FOUNDATIONS FOR URBAN RESILIENCE, ECOLOGICAL REHABILITATION AND HEAT MITIGATION

3.1 RETHINKING URBAN RESILIENCE: A FRAMEWORK FOR SUSTAINABLE ADAPTATION

Resilience is increasingly recognised as the ability of systems to absorb, adapt, and transform in the face of disturbances, ensuring core functions are maintained (Walker et al. 2004; Ahern 2011; Zeng et al. 2022). This capacity is essential for managing hazards in the context of climate change's growing unpredictability. In urban planning, resilience highlights the importance of long-term, preventative strategies that address complex and uncertain challenges, making it a vital approach to hazard management (Robinson 2001; Rasilia et al. 2019; García 2022).

Although resilience shares similarities with sustainability, it differs fundamentally in its principles and focus. Resilience, rooted in non-equilibrium theories, embraces uncertainty and prioritises adaptive, flexible processes rather than predefined goals (Ahern 2011). "Resiliency" has its etymological origin in the Latin verb resilio, which means "to jump back" (Semplici 2020). In contrast, sustainability traditionally relies on fixed objectives and linear progress (Leichenko 2011; Zeng et al. 2022). This distinction reframes resilience as a "new way of thinking" (Ahern 2010:145) rather than a prescriptive checklist, emphasising adaptability over stability.

Urban policies have begun incorporating resilience as a critical framework, particularly in climate planning. Jack Ahern's (2011) strategies (Figures 3.2 – 3.6) offer actionable principles for enhancing resilience and guide this study's exploration of heat mitigation.



Multifunctionality: Urban spaces should integrate diverse ecosystem services, addressing multiple needs simultaneously. The combination can be done by 'piling' or 'shifting' the functions.

(Bio)diversity: Biological, ecological, genetic, social, physical, and economic diversity enhances resilience by allowing varied responses capacity to disturbances and stress.

Redundancy: Decentralised systems ensure functionality through backup networks, spreading risks across scales. It could resemble a network of smaller functions.

Multi-scale Connectivity: Interconnected networks maintain functionality after disruptions, bridging urban and regional systems.

Adaptive Planning: Flexible, pilot-driven approaches turn uncertainties into opportunities, enabling iterative improvements.

It requires monitoring and analysing the results to adapt and improve the plans and designs.

Figure 3.2-3.6: Icons representing each strategy. Multifunctionality. Diversity. Redundancy. Multiscale connectivity. Adaptative planning.

These principles are applied to examine urban heat resilience. By aligning resilience strategies with urban heat mitigation, interventions can address the multifaceted challenges of heat stress while fostering adaptive, context-specific solutions. Ahern's framework serves as a foundation for translating resilience into actionable principles that improve urban heat management in Mediterranean climates.

3.2 ECOLOGICAL REHABILITATION: A FORWARD-THINKING APPROACH BEYOND RESTORATION

Ecological restoration aims to enhance ecosystem health by creating 'good conditions' that enable habitats to thrive by adapting, absorbing, and transforming in response to disturbances (European Commission, Directorate-General for Environment 2022; Zeng et al. 2022). Effective restoration requires careful analysis and planning, including species selection and substrate management.

The recently accepted European Restoration Law (European Commission, Directorate-General for Environment 2022), part of the EU Biodiversity Strategy (2020), emphasises ecological restoration as a solution to counter biodiversity loss, which has been pointed out as one of the principal aspects of enhancing UHI (Keith & Meerow 2022). The primary demand to member states is to implement "restoration measures to at least 20% of the land and marine areas by 2030". The proposal contains seven targets; between them is the urban environment. Cities are called to renaturalisation, and other degraded ecosystems, such as some forests, wet areas, or oceans, are called to restoration (European Commission, Directorate-General for Environment 2022), which entails critical differences.

Ecological restoration refers to "activity with the goal of achieving substantial ecosystem recovery relative to an appropriate reference model (…) informed by native ecosystems" (Gann et al. 2019:7). Ecological restoration can be active or passively assisted recovery, depending on the preexisting ecosystems, their state of degradation, and perturbations toward a healthy reference state (Klaus & Kiehl 2021; Ministerio de la Presidencia, Relaciones con las Cortes y Memoria Democrática 2021). However, guidelines in this restoration law differ between ecosystems, and cities enjoy exclusive considerations because they are classified as novel ecosystems due to their natural ecosystem depletion (Carrillo et al. 2018; Klaus & Kiehl 2021; European Commission, Directorate-General for Environment 2022). So, NbSs is proposed as the primary strategy for introducing more biodiversity in urban environments (European Commission, Directorate-General for Environment 2022), with all the consequences that imply integrating disconnected habitats in non-welcoming environments. However, rehabilitating these novel ecosystems (Gann et al. 2019; Klaus & Kiehl 2021) focuses on improving habitat biodiversity and other ecosystem functions without the goal of a pre-disturbance state (Klaus & Kiehl 2021).

Since there is not much information on rehabilitation for these novel ecosystems, another example that needs more study can be considered. Therefore, the published handy guide aiming to help the afforestation and reforestation process: "The Guideline on Biodiversity-Friendly Afforestation, Reforestation and Tree Planting by the European Commission" (European Commission 2023) can become a guide for this work and further studies aiming for ecological rehabilitation of urban environments.

3.2.1 *Afforestation and reforestation guidelines.*

The general structure of this guide distinguishes three stages and suggests actions to be taken before, during, and after the process. In earlier phases, it is essential to select the appropriate area without disrupting open ecosystems with high biodiversity, such as wetlands or older forests. Then, it is essential to assess the biodiversity and soil, identify the existing habitat or the most suitable one, and examine the intrinsic characteristics of the soil, such as its permeability, water-holding capacity, and nutrient availability.

Choosing an appropriate species is crucial for success. The primary focus should be on prioritising the use of locally adapted native species that thrive alongside local lichens and mycorrhizae and are better suited to the area's ecological and climatic conditions. Non-native species may also be used in smaller quantities if they are adapted to the local soil, climate, and habitat conditions. They can contribute to resilience to climate change or provide shelter for secondary and native species. However, it is crucial to avoid introducing invasive alien species . Even if its impact on biodiversity is debatable, assisted migration accelerates tree adaptability to climate change, such as utilising species from southern latitudes or lower altitudes. The final insight regarding species selection involves promoting the mix of species at various levels, both in individual scales or mixtures of small monospecific patches and at the landscape level. "No single species should represent more than 5% to 10% of the total" (European Commission 2023:31).

Finally, nurseries are critical in "promoting the production of native species and local ecotypes in different biogeographical contexts" (European Commission 2023:20).

Implantation operations necessitate the protection of both habitats and soils. Safeguard existing habitats and species by conserving pioneering species, retaining damaged trees and dead wood, maintaining biodiversity within stands, encouraging existing regeneration and understory, and avoiding the removal of stumps. The soil can be protected and enriched by steering clear of ploughing operations, refraining from using heavy machinery that may compact the soil, particularly during wet seasons, and avoiding nitrogen fertilisers, which have dire consequences for species diversity (European Commission 2023).

The guide's recommendations for maintaining a good quality and development process are grounded in effective monitoring. The aim is to assess and act against the potential damage that significant threats, such as forest fires and droughts, can inflict in the early years. Some considerations include managing competition during the first 3 to 5 years through mechanical methods, integrating grazing management plans, or protecting anticipated seedlings to ensure successful stand development and high biodiversity (European Commission 2023).

3.2.2 *Urban Forestry and the Miyawaki Method: Fast-Tracking Green Resilience*

Forestry in urban areas is increasing and gaining recognition as one of the NbS (Nature4Cities—NBS Visualization n.d.). Since the minimum ratio of canopy cover to be considered a forest is 30% (Vigo et al. 2005:184), urban forestry is gaining traction as a tool for improving heat resilience. It has been successfully applied in Melbourne, Australia, and London (City of Melbourne 2014; London Urban Forest Partnership 2020).

One promising method is the Miyawaki approach, which accelerates forest growth by planting trees densely (See Figure 3.7). This method has shown positive results in various environments, including a semi-arid Mediterranean region like Sardinia, where trees have thrived 11 years after planting (Schirone et al. 2011). Recent projects in Spain also demonstrate its potential: survival rates range from 70% to 83%, with trees growing approximately 60 cm annually, even in extreme heat (MiniSelva | SUGi n.d.). However, not all species would compete equally. Therefore, it is critical to notice the successional stage to improve plant community resilience by combining early and late-successional species (Schirone et al. 2011).

Table 3.1 integrates the findings from the restoration guideline and the principles for creating a Miyawaki forest into a guideline for rehabilitating urban areas with tree-dominated habitats.

Figure 3.7: One of the rooms at Millenium Skog in Malmo. This park was started in 2011 and isolated some areas to allow nature to take its course. In some cases, they just covered the ground, planted it very tightly together to create competition, and started the clearing process ten years later.

Table 3.1: A guide to ecological rehabilitation based on the Guide on Biodiversity- Friendly Afforestation, Reforestation and Tree Planting. (Source: European Commission 2023)

Stages	Goal	Considerations
Pre-previously.	Identify potential patches to be part of the GBI. (network of environmental features, natural, and semi-natural)	Analyse possible high-value existing ecosystems to be protected or already protected areas.
		Distinguish existing biodiversity and soil conditions. It will require a different approach.
	Identify already existing cooling islands in the territory.	
	Identify the most appropriate habitats.	Consider geomorphological characteristics.
Planning.	Delimitate the area of intervention. Urban and close rural.	
	Choose a suitable species related to soil condition, adaptability to climate change and habitat connectivity.	No single species should represent more than 5% to 10% of the total.
		Varied age
	Promote the production of native species and local ecotypes in nurseries.	
	Start with a pilot project.	
During the process.	Promote good practices to non-damage existing conditions.	Avoid heavy machinery.
		Do not plough
		Mulch the ground
	Promote clustered planting	
	Promote practices to engage the community.	
Support implementation and monitoring.	Initial irrigation under the first three to five years.	
	Mechanical control of competition.	
	Facilitate continuous learning and community participation.	

3.3 HEAT MITIGATION STRATEGIES: THEORETICAL INSIGHTS FOR COOLER CITIES

Urban heat impacts manifest across multiple scales. The medium and smaller ones—governed by landscape features, urban morphology, and vegetation presence—directly influence human thermal comfort since they directly impact local factors such as air humidity, breeze, and radiation (Negev et al. 2020). Moreover, researchers and urban planners emphasise the integration of green and blue infrastructure [GBI] as a pivotal strategy for mitigating urban heat, and the number of studies exploring this relationship has risen since 2015 . The reviewed literature associates certain variables with a specific scale in all cases, and it became the task of this section to collect them and categorise them into three interconnected scales: features, entities, and networks.

3.3.1 OPTIMISING INDIVIDUAL GREEN FEATURES FOR MAXIMUM COOLING.

The elements of GBI that influence energy dynamics in urban environments, including vegetation and supportive infrastructure, depend on their form and composition. Understanding these features is essential for effectively leveraging their potential to mitigate urban heat.

3.3.1.1 Cooling Potential and Challenges of Trees and Vegetation.

The cooling capacity of trees, particularly compared to shrubs and grasses, is well-documented (Shashua-Bar et al. 2011; Saaroni et al. 2018; Wheeler et al. 2019; Balany et al. 2020; Forman 2021; Iungman et al. 2023). Trees reduce peak temperatures and create microclimates under their canopy by shading and evapotranspiration (Figure 3.8). They store energy as latent heat, releasing moisture rather than heat (Gunawardena et al. 2017), in contrast to urban surfaces that trap and emit heat.

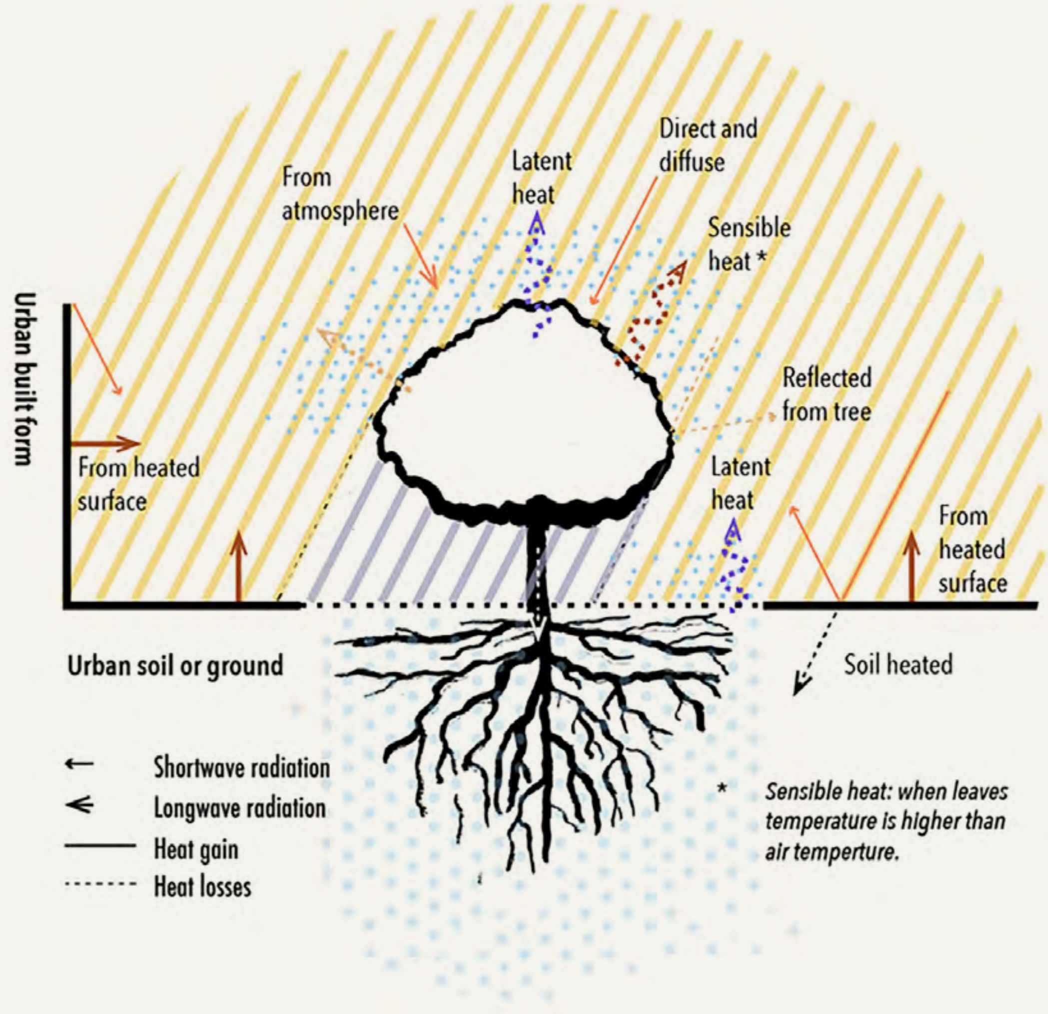


Figure 3.8: Energy exchange between a tree and an urban environment, based on Gunawardena et al. (2017).

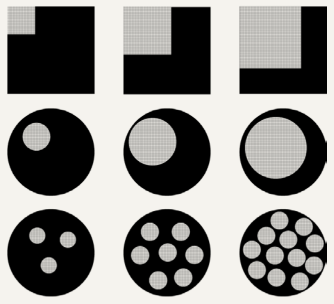


Figure 3.9: Illustrated proportion of 10%, 30% and 50% under three different configurations.

Tree Canopy Density: Striking the Right Balance

The canopy's coverage significantly impacts urban heat reduction (Gunawardena et al. 2017; Balany et al. 2020). The recommendations range from 10%, as proposed by the European Commission (European Commission, Directorate-General for Environment 2022), to 30%, which could reduce temperatures by up to 0.4°C and positively impact human health (Konijnendijk 2021; Iungman et al. 2023) (See Figure 3.9). Some studies calculate reductions of up to 4.4°C with 50% coverage (Imran et al. 2019). However, the meaning of these findings has a relatively open interpretation for implementation since they do not integrate shade density, distribution patterns, urban form, or geographical factors (Wheeler et al. 2019) into the equation.

Figure 3.10: Illustrated stillness of evapotranspiration under a group of tree canopies.

Urban environments challenge tree health with predominantly paved areas and soil compaction, causing difficulty in tree growth and premature mortality (City of Melbourne 2014; Embrén 2016). Moreover, sick trees may experience reduced canopy coverage, as their health status significantly influences heat absorption (Sjöman et al. 2015; Balany et al. 2020). Tree canopy density is also pivotal but can also be affected by non-heathy situations. While dense canopies provide shade, they may impede nighttime cooling in warm climates, as observed in species like *Ficus retusa* (Shashua-Bar et al. 2010). They can block nighttime air circulation (Figure 3.10), impacting overall cooling (Wheeler et al. 2019) because of losing cooling opportunities. Some authors suggest lighter canopy trees offer better cooling performance in urban settings than denser species (Figure 3.11). The study by Shashua-Bar et al. supports the evidence that temperatures begin to decrease earlier in restricted urban environments planted with *Tipuana tipu*, a lighter canopy compared to the *Ficus retusa* (Shashua-Bar et al. 2010). However, further studies are required to understand the varied performances of a broader range of species regarding leaf density, heat release, and airflow in their local context (Figure 3.12).

Figure 3.11: Illustrated lighter tree canopy allowing wind flow in an urban situation.

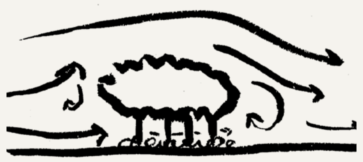


Figure 3.12: An illustrated group of isolated trees generating mechanical turbulence, based on Gunawardena et al. (2017).

Xerophytic Vegetation: Resilient and Reflective Solutions for Hot Climates.

Xerophytic species adapt to low-precipitation environments , offering unique heat mitigation benefits. Their silver, gold, and light green colours are usually characterised by high albedo colours(Imran et al. 2019) that effectively reflect solar radiation (See Figure 3.13). They also have **profound root systems**, so they develop channels in the soil that can enhance moisture availability for other plants (Tomaselli 1977). Additionally, their smaller and stiffer leaves can close their

Figure 3.13: Garrigue landscape showing Teucrium fruticans on the first plan.

stomata to minimise water loss (Font Quer et al. 2015; Wheeler et al. 2019), reducing transpiration and, thus, ambient humidity.

This observation challenges the general belief that increased vegetation consistently raises ambient moisture (Edmondson et al. 2016; Gunawardena et al. 2017). Thus, xeric species and landscapes' overall heat mitigation capacity necessitates further investigation.

3.3.1.2 Strategic Vegetation Layouts: Finding the Best Cooling Configurations.

Optimal configurations of urban vegetation balance heterogeneity and clustering. Two perspectives on vegetation configurations may initially seem contradictory but ultimately complement each other. Gunawardena et al. (2017) identified that "dispersed groves with canopy heterogeneity improve surface roughness to generate mechanical turbulence and thereby enhance convective heat loss" (Gunawardena et al. 2017:1043). In contrast, Wheeler et al. (2019) asserted that **"clustered vegetation cooled surface temperature more than dispersed vegetation"** (Wheeler et al. 2019:4), enabling cooperative tree growth (Anderson et al. 2015) and amplifying ecosystem services over time. Combining these approaches through heterogeneous clusters may maximise cooling and resilience.

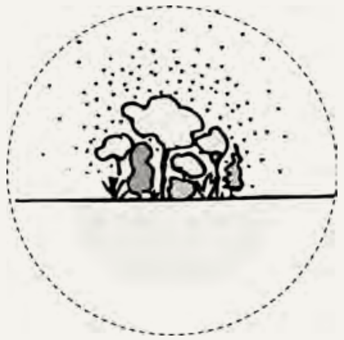


Figure 3.14: Illustrated heterogenous cluster composition.

Multilayering species—a mix of trees, shrubs, and ground cover— (Figure 3.14) performed best for human thermal comfort [HTC] (Imran et al. 2019). Although shrublands exhibit lower capacity than tree-dominated spaces (Imran et al. 2019), they still provide valuable ground shading (Balany et al. 2020). Grass offers high comfort but requires more water (Shashua-Bar et al. 2011), which is not always available. Multilayered plant species provide shade, prevent soil dryness, and facilitate water retention in dry climates. However, they can also create wind barriers, so they need to be applied at distances of about three times their height.

Techniques like mulching are used in regenerative agriculture, contemporary naturalistic planting designs, and forest restoration techniques, such as the

Miyawaki method. It is a protective buffer to protect soil from erosion and weed growth, enhance composting, accelerate soil creation (Schirone et al. 2011), and retain moisture. Mulching materials can range from mineral substrates, like gravel, to compostable materials, such as the fibre fabric used in the "Millennium Forest" reference project. Such strategies are essential for sustainable urban planting designs, particularly in regions with water scarcity.

3.3.1.3 Urban Soils: The Overlooked Foundation of Sustainable Greenery

"Soils are major providers of crucial ES since they contain one-quarter to one-third of all living organisms on the planet" (Ronchi et al. 2019:763). Urban soils are often compromised by c**ompaction, erosion, salinisation, desertification** and **pollution** (European Commission 2021), which directly impact the root system of urban trees (Kim et al. 2021).

Innovative methods like the Stockholm method have been developed to improve urban soil conditions in Nordic climates, ensuring tree necessities such as water, nutrients, protection, gas exchange, and space (Decades of Successful Urban Tree Plantings Research and Best Practice Based on the Stockholm Solution 2023). The 'Stockholm method' also includes larger stones to support tree stability, allowing root development in a compacting-stressed situation while exchanging gas with a supportive ventilation shaft (Embrén 2016). With this method, biochar improve water retention in urban soils with gravel-based substrates[7]. Using structural soils with gravel substrates in cities represents a huge potential for urban trees in many regions since roots might be protected from compaction. However, this solution remains unexplored in Mediterranean and dryer climates, even though Biochar has a long history in Mediterranean agriculture practices.

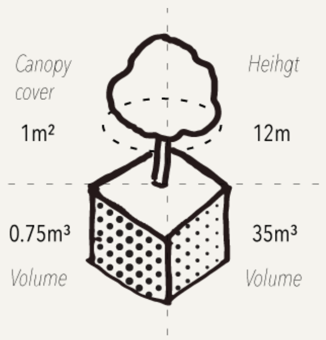


Figure 3.15: Proportion of above-underground space. (Schmidt and Grimm 2023).

The amount of underground space vegetation needs depends on the species. Good interaction between above and underground is fundamental to ensuring vegetation health (Alday & Martínez-Ruiz 2022). Figure 3.15 illustrates some of the standards used by Schmidt and Grimm (Schmidt & Grimm 2023).

7 The commonly used proportion of gravel-biochar is 75%-25% of 2-6mm for perennials and bushes and 85%-15% of 32-63mm for trees (Embrén 2016).

However, more studies are needed on Mediterranean regions, climate, and native species since xeric vegetation requires a larger underground volume than the aerial part (Font Quer et al. 2015).

3.3.1.4 The Role of Water Features in Reducing Urban Heat

Water features improve thermal comfort in dry areas by capturing heat from the air and reducing ambient temperatures. They have an average cooling potential of around 2.5°C (Gunawardena et al. 2017) but require strategic placement and shading to minimise evaporation and nighttime heat emissions (Hathway & Sharples 2012; Gunawardena et al. 2017).

Smart Rainwater Management: Harnessing Water for Cooling

Rainwater captured through a distributed network of vegetated beds supports sustainable water management in arid regions. Planting beds with rainwater capture is emerging as a viable alternative to decentralised water management systems. Moreover, minor interventions represent an opportunity be more distributed in the territory and unseal surfaces and include sustainable rainwater management (Forman 2021). These systems irrigate vegetation and can even replenish aquifers, which other water management systems can not do.

3.3.1.5 Artificial Green Infrastructure: Green Roofs, Walls, and Reflective Surfaces

Green roofs and walls can also contribute to lower urban heat (Keith & Meerow 2022) by minimising heat absorption in buildings by insulating them. These surfaces might not directly affect HTC at the street level (Carvalho et al. 2017), but their influence at a bigger scale requires more research. A cost-effective solution for reducing heat is white roof applications (Carvalho et al. 2017). However, they do not provide the additional benefits of boosting biodiversity, decreasing peak stormwater runoff, and reducing air pollution, such as green roofs (Keith & Meerow 2022).

3.3.2 COOLING ENTITIES: DESIGNING GREEN SPACES FOR EFFECTIVE TEMPERATURE REDUCTION.

Cooling entities are specific green patches that affect urban energy balance due to their layout, design, and maintenance. We will explore the last two here since the features and configuration are not much explored in the literature at this scale, and therefore, we have previously approached them.

3.3.2.1 Key Design Considerations for Cooling Patches

Size Matters: Finding the Optimal Scale for Urban Parks.

Larger parks generally achieve more significant cooling effects (Gunawardena et al. 2017; Forman 2021). Parks offer a Potential Cooling Intensity [PCI] ranging between 1,5°C and 3,5°C, independent of their size, form, or climatic region (Saaroni et al. 2018). Some studies suggest that parks over 500 hectares may achieve a PCI of 5°C (Forman 2021). However, even smaller parks can provide significant temperature reductions under optimal conditions; for instance, a small park in Lisbon (0.58 hectares) recorded a temperature difference of -6.9°C at peak hours (Saaroni et al. 2018). However, these studies would have been more relevant if analysing the configuration or ES they provide since, for instance, larger parks can sustain larger trees.

Figure 3.16: Illustration of linear green patches with a varied position to predominant winds.

Shape and Cooling Performance: Why Round and Square Parks Work Best.

Round or square parks tend to cool more effectively than linear parks. They enable "stronger temperature and humidity gradients necessary to effect citywide cooling" (Gunawardena et al. 2017:1045). Linear parks and green roofs may not cool as efficiently but can contribute to overall temperature regulation by providing additional shade (Keith & Meerow 2022) or participating in gradual heat transmission.

THEORETICAL FRAMEWORK

Cooling Corridors: How Green Spaces Influence Airflow and Heat Dispersion

Street orientation, wind direction, and building height influence the extent of cooling penetration (Gunawardena et al. 2017). When winds align with parks and canyon streets, they displace the cooler temperature from the park, generating a "park breeze"(ibid.) and relieving heat stress. However, street orientation also differentiates how the run radiation impacts the built environment. East-west directions are associated with more discomfort and heat stress, regardless of the aspect ratio [AR][8], due to the number of hours in the morning and evening when the street materials absorb heat (Ali-Toudert & Mayer 2006; Rodríguez-Algeciras et al. 2018; Balany et al. 2020).

3.3.2.2 Overcoming Maintenance Challenges for Sustainable Green Spaces.

Figure 3.17: Grass cutting with heavy machinery in the Segre River canalisation while watering.

Balancing Aesthetics, Ecology, and Resource Constraints

Increasing the number of green areas might overload municipality responsibility, and the economy related to maintaining public spaces might become one of the multiple implementation barriers. Additionally, lack of commitment and political priority are the main barriers the European Commission has identified in allocating budget and resources for restoration practices (European Commission, Directorate-General for Environment 2022). It is also well-understood how much criticism politicians fear; therefore, inaction can sometimes become their strategy. Still, an unmaintained perception of green spaces could be a reason for criticism, so neat spaces tend to combine with easy to maintain, directly reducing biodiversity (Nassauer 1995) (Figure 3.17).

8 AR= height/ width [H/W]

Collaborative Maintenance: Lessons from Girona's Shores

Collaborative projects like Girona's Shores demonstrate that innovative strategies can achieve substantial results within constrained resources. Details of this project can be found in *Appendix F: Reference Project Summary.* Franch and Lanzas (2020) integrated extensive natural and semi-natural areas at the city's edge into the green infrastructure framework. The prototype framework and a diverse maintenance strategy are the two exit keys. It started with a minor intervention in collaboration with municipal workers to create a diverse maintenance strategy to streamline their resources while generating hotspot maintenance guidelines. This prototype project showed that substantial results could be achieved within limited budgets while managing resources differently.

Reducing maintenance is also a central aspect in some schools of natural planting design, particularly those with technocratic approaches (Kingsbury 2008; Dunnett 2019). Selecting native and other bioregional species can reduce maintenance requirements[9] since they are suited to specific biogeography and share habitat characteristics. With recommended species densities of 15-20 per square meter (Kingsbury 2008:61), it also enhances biodiversity. Furthermore, sowing native species can reduce maintenance even more[10] while restoring larger surfaces (Kingsbury 2008). However, expertise is required among maintenance staff, as well as careful soil preparation and specific native species seed mixes, necessitating further research, particularly in the case study region.

9 5-8 min/m2/year

10 around 4 min/m2/year.

3.3.3 EXPANDING COOLING BENEFITS THROUGH GREEN NETWORKS

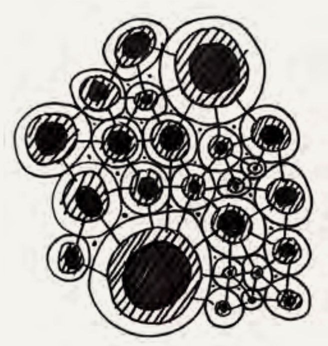


Figure 3.18: Illustrated network of nodes with buffer zone at an exact distance between them.

At a larger scale, GBI works as a strategically planned network of interconnected "natural and semi-natural areas with other environmental features, designed and managed to deliver a wide range of ecosystem services while enhancing biodiversity" (Green Infrastructure - European Commission 2023). This definition is vital in highlighting the essential role of **planning, designing,** and **managing** the entities and their composition in a manner that can yield more significant benefits, in this particular case, microclimates, heat mitigation, and airflow convection. At this scale, two topics require special attention: how these entities connect and how they can be integrated into the planning process.

3.3.3.1 Green Corridors: Enhancing Cooling Capacity Through Connectivity

Supposing that entities in this network have cooling capacity, interconnectivity has the potential to expand their functions and capacities to a broader scale (Gunawardena et al. 2017; Saaroni et al. 2018; Imran et al. 2019; Balany et al. 2020; Iungman et al. 2023).

How entities are connected can enhance or facilitate function dispersal in the system. Generally known as green corridors, they foster biodiversity, enable wildlife movement, and are essential in ecological thinking and planning (Davies et al. 2015; Forman 2021). They promote environmental interactions and enhance species survival, facilitating pollination and seed dispersal, which is vital for maintaining healthy ecosystems (Goicolea et al. 2022). Both physical connectivity (proximity) and structural similarity (habitat coherence) are critical for optimising these networks (Forman 2021).

Community Involvement: A Key Factor in Long-Term Success

Community engagement is vital for the success and sustainability of GBI networks (Keith & Meerow 2022). Engaging residents in the planning and maintaining of green spaces fosters a sense of ownership and encourages stewardship, while educational initiatives build public support for long-term sustainability. However, they require a well-structured and transparent strategy planned from the municipality and integrated into the planning strategy to identify and guide stakeholders in the design and implementation stages.

Integrating GBI into Urban Planning for Climate Resilience

Integrating GBI into urban planning can optimise cooling effects and align land-use policies with resilient strategies. However, designing and incorporating new planning processes extends beyond this work. Nonetheless, it is essential to acknowledge the literature's findings on resilience and the potential role of GBI planning.

The first national strategy to plan green infrastructure in Spain was relatively recent (Ministerio de la Presidencia, Relaciones con las Cortes y la Memoria Democrática 2021), and since then, major cities have introduced GI planning as a municipal strategy. However, smaller municipalities are still eager to do so (Ministerio para la Transición Ecológica y el Reto Demográfico 2021). Green plans have been developed in Sweden for over forty years, becoming a critical supporting material for comprehensive plans, building structures, and traffic infrastructure development (Kristianstad Municipality & Movium Think Tank 2020). Green plans serve as overarching strategic documents that require defining and framing the area of interest (Kristianstad Municipality & Movium Think Tank 2020). They provide guidelines, strategic maps, and action plans (Kristianstad Municipality 2020) to assist decision-makers (Davies et al. 2015). For example, Gothenburg's green strategy is supported by park plans, a national conservation strategy, an outdoor activities program, ecological landscape analyses, an urban environmental policy, a tree policy, a playground policy, compensation, and additional programs and policies (Kristianstad Municipality & Movium Think Tank 2020:67). Many practitioners support the idea of interconnected documents, which mutually support each other and allow for simplified elements that can be readily adapted to manage uncertainty and align with resilience strategy thinking (Ahern 2011; Keith & Meerow 2022).

Under this framework, the Green Plan could be a potential platform to plan heat resilience strategically. According to PhD Ladd Keith and PhD Sara Meerow (2022), when planning to increase urban heat resilience, heat mitigation and heat management strategies should be incorporated together and supportive; "cooling communities through vegetation or design of the built environment and (…) reducing heat risks through emergency response or social services" (Keith & Meerow 2022:38). This means that supportive strategies would have more impact. Planning and designing approaches to lessen the effect of heat, such as reducing the waste and emitted heat of roofs and pavements, while improving cooling opportunities.

3.4 BRIDGING RESILIENCE, ECOLOGICAL REHABILITATION, AND HEAT MITIGATION: KEY INSIGHTS, CONTRADICTIONS, AND RESEARCH GAPS

Emerging strategies to reduce heat stress indicate that interventions at multiple levels can yield positive outcomes for cities. For instance, creating local microclimates improves human thermal comfort, and interconnected cooling islands in a well-connected green network maximise ecological benefits and ecosystem services. However, research on how green spaces function as cooling islands has revealed contradictions and gaps that require further investigation, particularly regarding patch composition, species selection, and structural configuration.

Although divergences exist between resilience thinking and ecological restoration, ecological rehabilitation emerges as a particularly relevant approach to introducing biodiversity and improving ecosystem functions. While resilience emphasises adaptability, decentralisation, and multi-functionality, restoration often seeks to return ecosystems to a pre-disturbance state. This fundamental tension means restoration may focus on historical fidelity, whereas resilience embraces change and transformation. Ecological rehabilitation bridges this gap by prioritising biodiversity and ecosystem functionality without rigid historical constraints (Klaus & Kiehl 2021). This distinction is particularly relevant for urban environments, where ecosystems have been profoundly altered.

A key contradiction in urban ecological rehabilitation lies in balancing biodiversity improvement and heat mitigation within green patches. While increasing vegetation cover is widely recognised as a heat mitigation strategy, the type, structure, and spatial arrangement of vegetation determine its ecological and climatic effectiveness. Tree-dominated green spaces provide cooling through shading; however, they may not always create suitable habitats for local biodiversity, especially if they replace historically open or dry ecosystems rich in biodiversity. Thus, the initial point in the Afforestation Guide was correct in highlighting the importance of site selection. Some xeric ecosystems in Lleida are biodiversity hotspots that support species adapted to arid conditions, yet their effectiveness in mitigating heat remains uncertain. Certain species enter dormancy during extreme heat, which reduces evapotranspiration. Conversely, their root systems enhance soil structure and prevent desertification, elements that remain underexplored in heat mitigation research. Furthermore, a dense forest with a thick canopy could conflict with urban cooling needs, as it may trap heat at night instead of releasing it. Identifying the most suitable ecosystem requires adaptation to the local conditions regarding urban form, morphology and existing habitats. Patch configuration in heat mitigation remains a critical research gap that requires more attention.

The interconnectivity and influence of a cooling island's potential have not been clearly addressed in the literature, as this complex issue depends on the surrounding environment, wind directions, and barriers, as indicated by distant temperature monitoring in Gunawardena et al.'s (2017) study. However, the absence of local temperature monitoring has been identified as a significant research gap, which hinders efforts to optimise rehabilitation strategies for climate resilience. Although this study does not conduct direct temperature monitoring or species selection analysis, it synthesises key design principles from the literature. By addressing these gaps, this research contributes to the development of rehabilitative HRGBI for Lleida and lays the foundation for future empirical studies on long-term urban resilience.

CHAPTER

4

A REHABILITATIVE HEAT-RESILIENT GREEN-BLUE INFRASTRUCTURE PROTOTYPE

4.1 CRITICAL CHARACTERISTICS AND PRINCIPLES OF A REHABILITATIVE HRGBI

"A strategically planned network of redundant and multifunctional natural and semi-natural areas designed and managed to support the ecosystems that can locally regulate climate while establishing multiple-scale connections to ensure biodiversity".

This definition is derived from the European Commission's concept of green-blue infrastructure, which emphasises the design and management of natural elements to generate functions, hence, ecosystem services [ES]. To foster heat resilience, regulatory ES are crucial to securing this benefit, while supportive ES are essential for ensuring the ecosystem's health. Without excluding the other two, a rehabilitative HRGBI needs to focus on promoting regulatory and supportive ES.

From a resilience perspective, this network must be planned to provide several functions distributed around the area that overlap and repeat under varied conditions. Identifying the existing functions should be the first step in determining what local functions are in place and how they can be replicated. Moreover, a variety of strategies from a planning perspective would imply the integration of direct and supporting interventions, such as those focusing on reducing heat intake with green roofs in urban environments. Finally, adaptative planning implies a modularity of design and interventions in a continuous learning process.

Part of the overarching design questions indicates that areas exceeding 200 square metres and exhibiting either a round or square shape have a greater cooling potential that can be effectively distributed if they are roughly 300 metres apart. These areas must consider promoting air convection, reducing heat absorption, balancing evapotranspiration and ensuring ecosystem health and long-term results. These four groups of principles must be considered when planning and designing the network and its patch part. Figures 4.1 to 4.20 represent icons of the principal strategies extracted from literature and collected here to complement the definition of a rehabilitative HRGBI.

Assure long-term results.

Multifunctionality.

Include diversity of forms and sizes since forms and functions are related. Round or square parks have more cooling capacity than linear parks. Bigger ones allow more significant species and integration of varied functions, while smaller ones can be supportive.

Diversity of mitigation strategies.

A modular system allows them to supplement each other, such as green roofs and parks.

Redundancy of function.

Avoiding uniqueness of functions along the network.

Multiscalar connectivity.

Interconnected functions and patches along the system.

Adaptative process.

Include community involvement and procurement. Engage local communities.

Promote Air Convection

Wind Direction.

Wind can move cooler air horizontally from a cooling area through aligned canyon streets. Consider predominant wind direction under summer since this wind can potentially reduce temperatures by moving heat horizontally.

Wind Barriers.

Buildings and vegetal elements can offer a barrier to the wind in a proportion of 1/3 (H/W). Creating or avoiding still areas must be considered under site-specific design requirements.

Green Corridors.

Support city-wide cooling while creating biodiversity connections between fragmented green spaces where species can move through and improve the system's resilience.

Mechanical turbulence.

Surface rugosity generates wind turbulences necessary to mobilise airflow. Dispersed groves or grouped clusters increase mechanical turbulence for better heat loss.

Light-leaved tree species.

They allow air circulation during the night in narrow situations in warmer climates.

Reduce Heat Absorption

Canopy coverage.

The canopy covers between 30% and 50% of the surface, depending on the urban context and species development.

Multi-layered Planting.

Combine trees, shrubs, and grasses to create shade and water retention on a multilayer scale. It can generate wind barriers and contradict the wind flow principle, so it needs to be applied locally, considering both variables.

High albedo .

Xerophytic plants usually have high albedo colours that better reflect radiation while being drought resistant. Hard surfaces with high albedo reflect light but can be hazardous to eyesight.

Green Roofs.

They enhance insulation and lower heat emitted from extensive roofs or denser urban areas. White roofs are a cost-effective alternative.

Green wall.

Applied on west façades, they reduce absorptions and provide insulation.

Balance Evapotranspiration

Rainwater harvesting.

Canalise rainwater to planting beds so plants can be irrigated. The proportion of urban area and planting requires further species and substrate selection research.

Permeable surfaces.

Increase the proportion through planting beds and other plain surfaces that allow water to infiltrate.

Shaded Water Features.

Water bodies with shading minimise evaporation while enhancing cooling potential, especially in arid regions.

Concave shapes.

This shape allows water and humidity to accumulate, which is critical in arid regions. However, infiltrating water during rainy periods needs good draining capacity.

Mulching.

Do not let the bare earth have direct contact with the sun. Gravel or compostable materials form a layer that retains soil moisture. Ideally, it should be a high albedo colour to reflect light radiation.

Xeric species.

Native plants have a long root system that creates water canals, allowing water to infiltrate better, even if they dry out during summer.

Ensure ecosystem health

Suitable species.

Choose species according to the local situation. Consider density, native vegetation, and available area.

Below-ground space.

Especially for tree planting, ensure a good volume for tree roots at a ratio of 0.75 m3 for every square meter of mature tree canopy cover.

Vegetation cooperation.

Promote clustering vegetation so their root system and other underground species can cooperate.

Soil improvement.

According to the existing situation, soil must require nutrient or structural improvement, particularly in urban environments, where compactation requires intervention.

Figure 5.1: A partial view of the Lleida landmark with vegetation depicts an illusional perception of the city where history and nature meet.

CHAPTER

5

ANALYSIS OF THE EXISTING SITUATION.

PRESENTING THE CASE STUDY: LLEIDA.

Figure 5.2: A representative section of the city from northwest to southeast, traversing the urban area, Seu Vella Hill, the Segre River Canalisation, and its rural surroundings

5.1 UNDERSTANDING LLEIDA'S HEAT STRESS: GEOGRAPHIC, CLIMATIC, AND URBAN INFLUENCES

The case study is presented here through the factors that Keith and Meerow (2022) identified as key characteristics impacting the UHI effect, including geography, loss of natural ecosystems, climatology, materials, heat emissions, and urban form. Sometimes, Lleida is presented as a flat territory with a historic city with strong connections with its natural surroundings (See Figure 5.1). However, it is a highly complex ecosystem, with subtle topographies (Figure 5.2) and other particularities that shape the city's vulnerability to heat stress and underscore Lleida's challenges in tackling its UHI effect.

5.1.1 *Geographic Features: The Role of Topography in Urban Heat Distribution*

Figure 5.3: A city nestled between two hills. Photo from Gardeny Hill capturing the Seu Vella atop the hill with the town below. Picture taken during exploration no. 2.

Geographic features such as hills, valleys, or water bodies affect local temperature variation by causing variations in wind patterns in the local area (Keith & Meerow 2022), with a relatively flat topography with punctual hills distributed around the territory. It is exposed to wind hills and stagnant river valleys.

The area embraces two hills: Seu Vella Hill, 199m.a.s.l.; *Gardeny* Hill, 198m.a.s.l. (Figure 5.3), with significant cultural and archaeological remains. Seu Vella is the old church that coronates this central hill with the same name and represents the landscape landmark of Lleida (Figure 5.1). *Gardeny* also contains remnants of *Gardeny* Castle and an active military fort until 1996, which was reused for small industries. This combination of use and topography can amplify the symbolism of the areas since elevated points in the landscape are informally used as meeting points, as seen in Figure 5.4.

Figure 5.4: Waiting for the sunset from Seu Vella Hill's western top. Under clear evenings, groups of people encounter at this point to enjoy the views. Photo taken under exploration no. 4.

The lower areas align with the riverbanks at 140m a.s.l., corresponding to the Segre River, which flows through the city from northeast to southwest and is canalised when crossing the city.

5.1.2 *Ecosystem Loss: Historical and Contemporary Impacts on Urban Resilience.*

Figure 5.5: Plan of Lleida from 1806 illustrating the natural river flow, a fortified town with agricultural surroundings. Isolated trees between crops, regularly planted ones and massed forests by the river and north of the city. (Moulinier 1806). (CCO)

Urban areas frequently emerge in ecologically sensitive regions, harming rural landscapes and causing ecosystem loss (Observatori del Paisatge 2006; Keith & Meerow 2022). Ground disturbance, soil compaction, and sealing affect the most biologically active layer: the topsoil (Edmondson et al. 2016). Root systems are hardly impacted; therefore, trees planted in challenging urban conditions have a lifespan of ten years (City of Melbourne 2014). Soil degradation and root pulling have been linked to desertification (Tomaselli 1977).

Figure 5.6: Exposed Major Canal between the urbanised area of Ciutat Jardí on the left and the rural Vallcalent on the right. Photo taken under exploration no. 1.

Lleida has a history of landscape disruption (Figure 5.5). During Romanization (218 B.C. to 500 B.C.), extensive deforestation occurred to cultivate almond and olive trees and vineyards. Landscape transformation peaked with the construction of the water canal (Figure 5.6) during the 8th century. After centuries of diseases, reconquests, and wars, the 19th century saw further changes through land confiscation, expropriating 'unproductive land' from the Catholic Church to support middle-class farmers, and more water canals transforming dry land into irrigated farmland (Observatori del Paisatge 2010; Spanish confiscation 2022). Land transformation continues, with urban sprawl and industrial areas, urbanising and sealing the ground to satisfy the expansion needs.

5.1.3 *Climate Profile: Heat Extremes, Rainfall Patterns, and Wind Influence.*

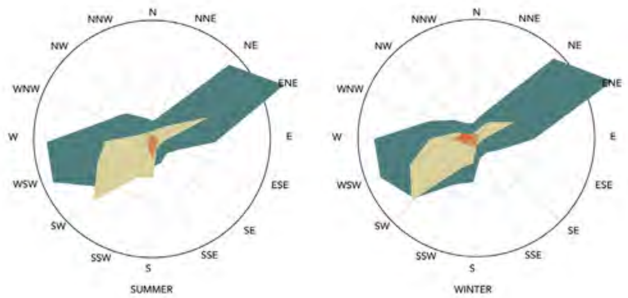


Figure 5.7: Predominant wind direction in summer and winter. Although lower wind speeds (0,5 m/s to 2.5 m/s) are similar year-round, there is an evident variation between the 5m/s to 7,5 m/s. (Meteocat 2023)

The climate of Lleida is Mediterranean, with a solid continental and semi-arid influence. This climate zone is semi-arid, with warm summers and cold winters (Kottek et al. 2006).

Wind is the meteorological variable that governs the UHI intensity, followed by solar radiation, which is

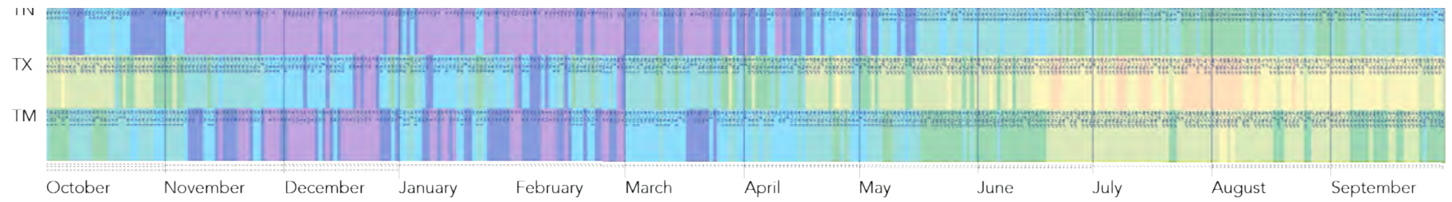


Figure 5.8: Physiological Equivalent Temperature [PET] for minimum temperature -TN-, medium temperature -TX-, and maximum temperature -TM- between October 2017 and September 2018. AEM XW. (XEMEC temperatures, 2018).

influenced by cloud coverage daily (García 2022; Keith & Meerow 2022). Lleida's yearly average wind speed is 1.24 m/s[11], and the predominant wind direction is northwest-southwest. However, stronger winds from the south can occur in summer, while stronger winds in winter come from the west and northwest (PCCL 2019; AEMET n.d.) (see Figure 5.6). This finding suggests that the western and southwestern regions need particular attention for study and proposal.

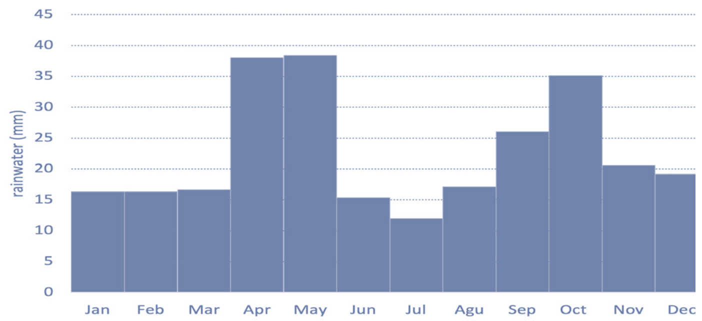


Figure 5.9: Monthly average rainfall measures at Lleida-La Bordeta meteorological station 165m/ 10 years). Rainfall can triple during the spring and autumn seasons. (Conesa Mor & Pedrol Solanes 2007).

The PET representation of Figure 5.8 shows a classic continental climate with extreme stress seasons, with colder months between December and February and warmer months from June to August, with a maximum absolute temperature of 43,4°C registered on the 29th of June 2019, and the minimum absolute registered was minus 14,2°C on the 8th of January 1985. The yearly average temperature is 15°C[12]. The most comfortable seasons are between May and mid-June and September and October; the rest include high-stress temperatures. Many days between June and October are marked as comfortable PET in the minimum temperatures [TN], which indicates high night temperatures during an extended period, even concerning the station localisation.

Figure 5.10: Fruit trees under the winter mist.

Although rainfall fluctuates between seasons (Figure 5.9), it maintains an annual average of 300 mm. The yearly average relative humidity is 64.2%, increasing considerably in winter and decreasing in summer.

Under high-pressure periods, the whole river basin area experiences a thick mist associated with Lleida's winter (Figure 5.10), but it is less and less present. These events also propitiate high levels of particulate matter (< 10 pm) accumulated (Gunawardena et al. 2017; PCCL 2019), which poses a severe health risk for the population, especially when there is no protocol activation.

11 Source: AEMET station: Lleida 2. Reference period: 1983-2010. Distance to Lleida centre: 3 km. NW

12 Source: SMC. Station Pla de Lleida.

5.1.4 *Urban Materials and Heat Retention: A Thermal Analysis of Lleida's Surfaces.*

Figure 5.11: Ronda Street is one of the wider streets in Lleida, exemplifying a sealed surface with asphalt and concrete. The colours exaggerate the heat absorption of the material. Photo taken under exploration no. 1.

The materiality of cities directly affects the surface temperature, which is the variable that generates more thermal alterations daily; meanwhile, air temperature is more stable (Keith & Meerow 2022) (Figure 1.3).

Asphalt, one of the most commonly used materials, together with concrete and other dark pavement surfaces, has a high inertia and low albedo, critically contributing to heat absorption (Figure 5.11). Together with building roofs, all the sealed materials in cities accumulate heat from solar radiation and release it after sunset, contributing to increasing aerial temperatures (Gunawardena et al. 2017; García 2022; Keith & Meerow 2022).

5.1.5 *Waste Heat Emissions: The Hidden Contribution of Human Activity to Urban Warming*

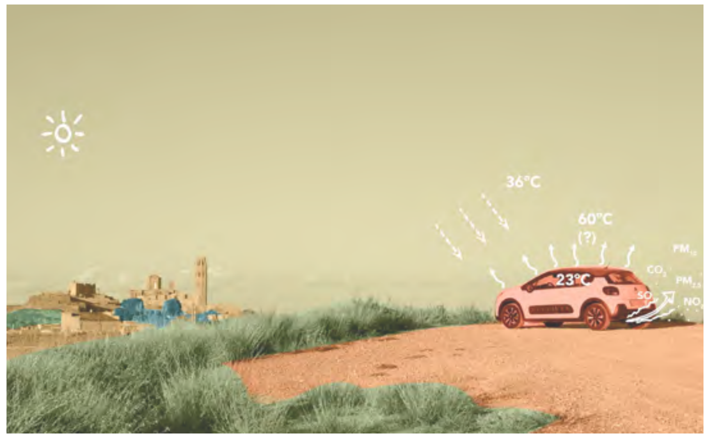


Figure 5.12: Car parked on the top of Gardeny Hill looking towards Seu Vella Hill. Using the photo taken under exploration no. 4, the colour and superposed illustration show how vehicles' materiality and emissions contribute to the UHI effect.

Current behaviour adaptations under heat waves or other extreme heat situations imply the extensive use of cooling machines and private vehicles. This has become mainstream behaviour in Lleida, where private vehicles are used daily (PCCL 2019), with the consequences of terms of materiality, heat emissions and pollution as Figure 5.12 illustrates.

Additionally, the increase in cooling systems during extreme periods raises the electricity demand and puts the system at the limit, if not wholly collapsing. During these events, machines also become heat emitters, adding to the general warmth (Keith & Meerow 2022). This is a clear example of maladaptive strategies since they increase the system's vulnerability (ibid).

5.1.6 *Urban Form and Microclimate: How Street Layouts and Building Density Affect Heat Stress*

Urban form guides how sun radiance arrives on materials and wind flow in the street (Keith & Meerow 2022). Street proportion, aspect ratios [AR] (H/W), and orientation are the main features that influence microscale energy balance (Balany et al. 2020). (Figure 5.13) The serpentine and narrow streets of the old town create shading possibilities[13], similar to some portico areas for a broader part of Major pedestrian street. Various authors noted that medieval and compacted cities suffered less stress because of the possibility of street shade (Gunawardena et al. 2017; Rodríguez-Algeciras et al. 2018; Balany et al. 2020; Keith & Meerow 2022). Balany et al. (2020) state that porticoes and higher AR reduce heat stress at the street level. However, it does not consider the energy balance at the city level (Figure 5.14).

Figure 5.13: Comparison between three aspect ratios [AR]. From top to below: AR 3 in the historical part, AR 0,8 encountered in Pius XII Street, and AR 0,18 in Ciutat Jardí.

Conversely, more modern areas, particularly those following sprawling development patterns, such as Ciutat Jardi[14], are characterised by broad, straight, unshaded streets and large sealed surfaces, which absorb and retain more heat.

Figure 5.14: Illustrative section representing the surface roughness generating wind perturbations, based on Gunawardena et al. (2017).

East-west-oriented streets, prevalent in certain parts of Lleida, experience prolonged sun exposure throughout the day, exacerbating heat absorption. Studies have shown that streets oriented in these directions are particularly vulnerable to higher heat stress (Ali-Toudert & Mayer 2006; Rodríguez-Algeciras et al. 2018; Balany et al. 2020). An example of this situation could be Avenue *Pius XII*[15] in the La Mariola neighbourhood, with a varied street section (See Figure 5.15).

13 Cavallers Street, and Major Street, AR=3 (15/5).

14 Olivera Street, AR=0,18-0,27 (4/22-6/22)

15 AR1=1,14 (24/21), AR2=0,81 (21/26) and AR3=0,7 (21/30)

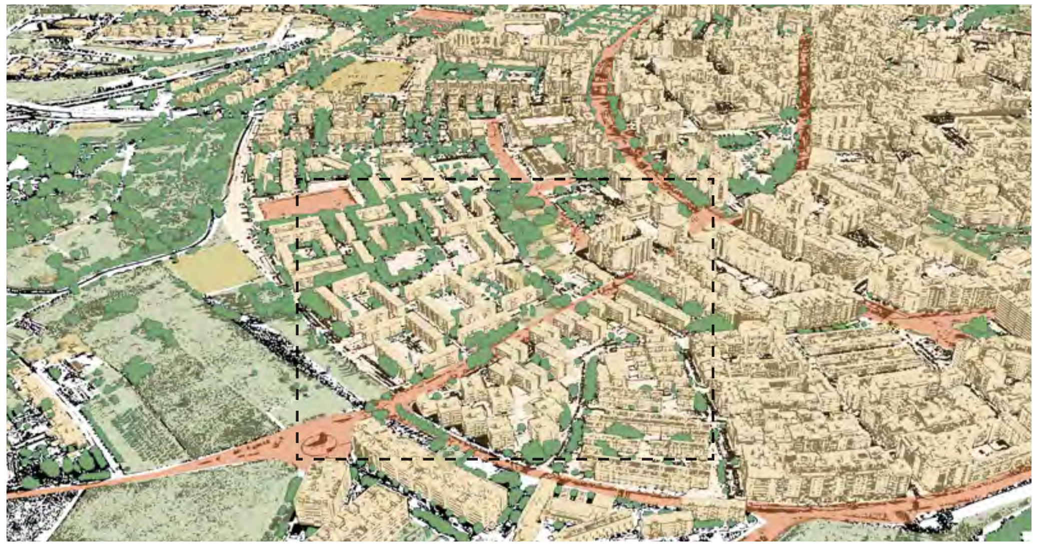


Figure 5.15: Axonometric view of the neighbour of La Mariola, which corresponds to the western part of the city with highly vulnerable communities.

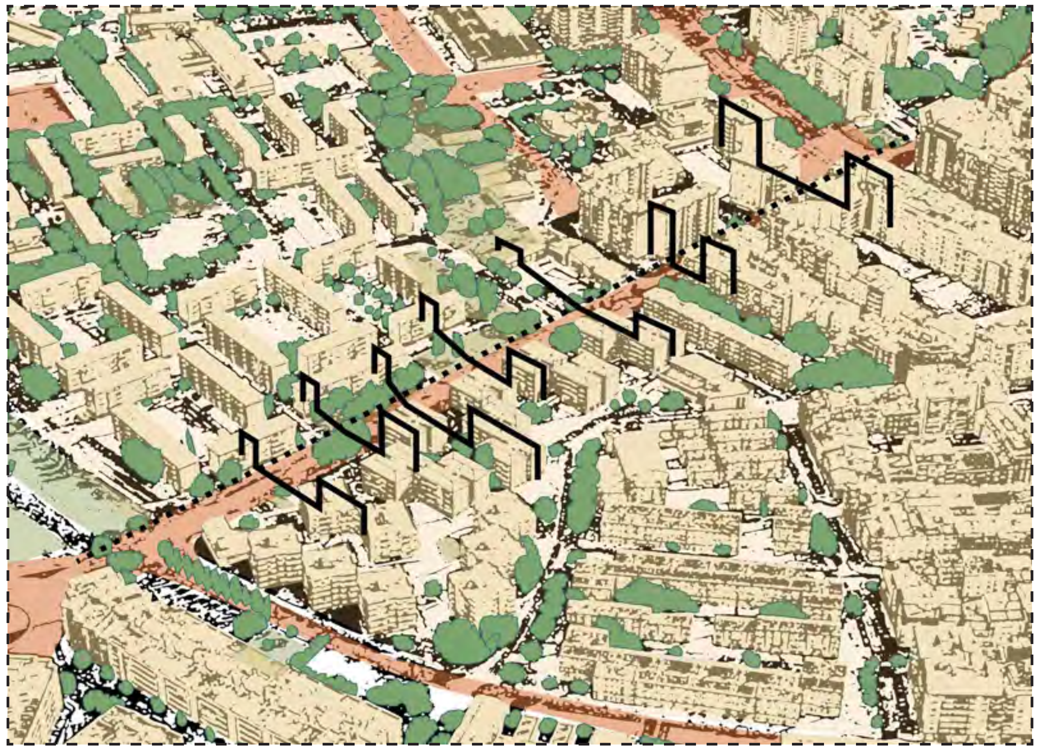


Figure 5.16: Avenue Pius XII axonometric view with a variation of AR.

5.2 ECOLOGICAL CONSIDERATIONS IN URBAN PLANNING: GAPS, STRATEGIES, AND CHALLENGES.

The analysis of planning documents revealed gaps in Lleida's urban strategies. While the 1999 General Plan remains active, more recent documents, such as the 2018 Municipal Planning Plan, have yet to be approved. Reviewed plans also included the 2019 Climate Change Plan and recent urban greening initiatives.

The municipality of Lleida is experiencing a planning crisis. The active planning document remains the General Plan 1999 [GP99], designed for 1995–2015. Despite significant socio-economic and ecological transformations since then, no definitive replacement has been approved. Although a new General Plan [GP18] was proposed in 2018, political forces have yet to validate it. Adding to the complexity, some documents, such as the Plan of Climate Change of Lleida [PCCL19], reference GP18 as a framework, creating a confusing situation.

To address this, the municipality has adopted a piecemeal approach, punctually modifying the GP99 and publishing updates on its website (Ajuntament de Lleida & Dep. Planejament i Gestió Urbanística 2022). However, the urgent need for a flexible, comprehensive plan that integrates current challenges remains unmet. This planning gap is one of the motivations for selecting Lleida as a case study.

5.2.1 THE MISSING GREEN AND BLUE INFRASTRUCTURE [GBI] PLAN: A CRITICAL OVERSIGHT IN URBAN STRATEGY

Municipal plans currently do not include GBI. Instead, Urban Free Space [UFS] defined areas free from development (Figure 5.17). The UFS system concept refers to all spaces that provide cultural and ecological functions (art. 143 sec. 7) and includes parks and green zones or gardens, urban green areas or squares, free linear spaces, and sport green areas (Ajuntament de Lleida & Dep. Planejament i Gestió Urbanística 2022).

As part of the system of UFS, we can find three urban parks (Seu Vella Hill, Gardeny Hill, and Segre River Canalisation), three significant green spaces (*Camps Elisis, Parc de l'Aigua*, and *Jaume Morera* Gardens), three urban forests (*Balafia, Magraners, and Cappont)*, the natural area of La Mitjana Park, in the metropolitan area. Also, every neighbourhood has a network of smaller squares, boulevards, and playgrounds. The unique considerations about ES or management are on the working document 'Plan of the Green', described in *Appendix H: Newly municipal documents.*

According to municipal data, Lleida's green

spaces account for 187,87 ha (2017) (PCCL 2019). The municipality claims a green ratio of 17,11m2/inhabitant (PCCL 2019; paeria.es n.d.). This is a relatively high ratio compared with what WHO recommends: 9 sqm/inhabitant (WHO 2020). However, there are no qualitative considerations in this measurement. Since the definition of UFS is quite broad, areas that contain vegetation but are inaccessible, such as roundabouts or the sites of the roads, might also be accounted for. Figure 5.17 illustrates Lleida's urban green space distribution, independent of the ES they provide and without incorporating agricultural land.

The PG99 proposed nine Special Plans[16] to be further developed (Ajuntament de Lleida & Dep. Planejament i Gestió Urbanística 2022). Some plans, such as the Special Plan for the Segre River, have not yet been applied, and others, such as the Director Plan for Ecological Corridors or the Director Plan for Ambiental Intervention Areas (Ajuntament de Lleida & Dep. Planejament i Gestió Urbanística 2022), have not yet been produced.

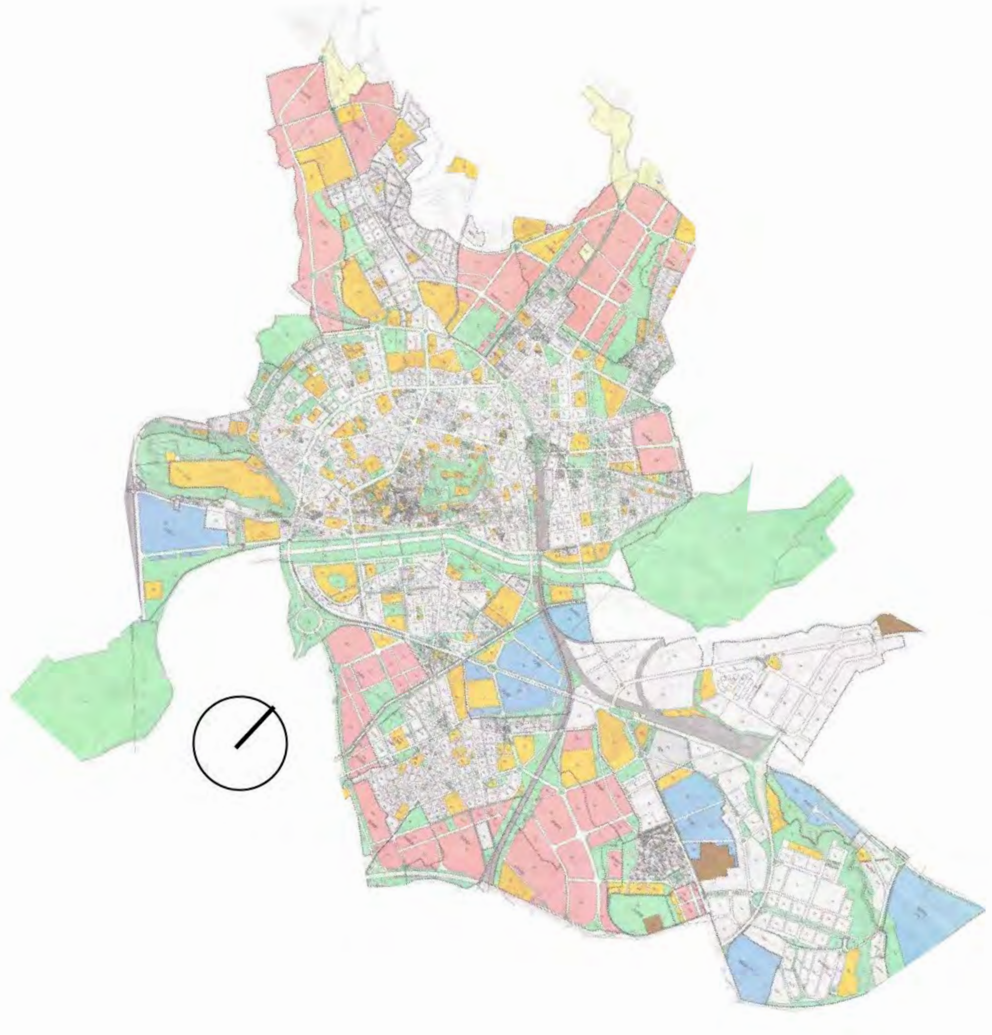


Figure 5.17: Lleida's urban green spaces from the PG99. (Ajuntament de Lleida 2022).

16 (1) Pla Especial del Riu Segre -Special Plan for the Segre River-, (2) Plans Especials dels Parcs Territorials -Special Plan for Territorial Parks-, (3) Pla especial de les Basses, (4) Pla especial de la Cerdera, (5) Pla especial dels Boscos de Raïmat, (6) Pla especial de l'aeroport, -Airport Special Plan- (7) Pla especial de la variant nord, -North route-(8) Pla director del camins de l'horta, -Paths l'Horta-, (9) Pla director dels corredors ecològics -Ecological Corridors-, and (10) Pla director de les àrees d'intervenció ambiental -Director Plan of Ambiental Intervention Areas-

According to Bellet and Llop, the PG99's big goals were "*protecting the natural heritage, l'horta model and the city centre*" (Bellet & Llop 2022:429). However, its effectiveness must be questioned for an already degraded original natural ecosystem, and the Horta model has been mutating from periurban food production to periurban city expansion (Aldomà Buixadé 2012). The historic centre has also suffered from degradation without a plan to protect it, which puts the protection model's capacity in question.

The ecological protection map supporting PG99 shows that many protected areas align with the main city infrastructures (Figure 5.18), specifically roads, without logic or integrating areas designed for 'natural interest' or 'habitats of communitarian interest' (Figure 5.21). This results in fragmented and dispersed, ecologically protected areas at the regional and national levels, with planning hands to define them. For instance, the Natural Reserve of Mas-de-Melons has double protection, the Plans of Special Natural Interest [PEIN], and Nature 2000 (Xarxa Natura 2000), in an extended area of 7608ha with seven habitat types and 60 protected species, in their majority birds (Associació Trenca 2021; EUNIS -Site factsheet for Secans de Mas de Melons-Alfés n.d.).

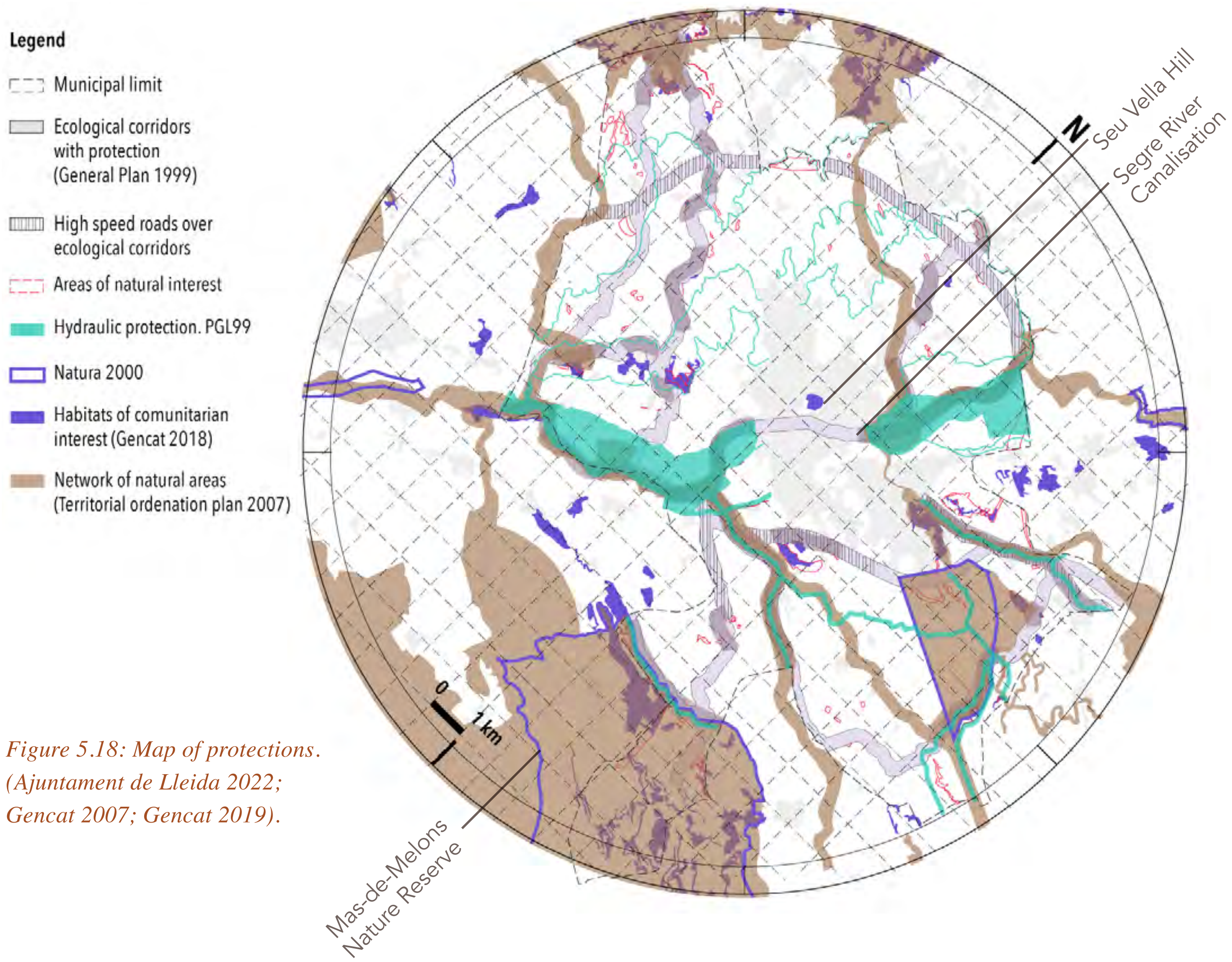


Figure 5.18: Map of protections. (Ajuntament de Lleida 2022; Gencat 2007; Gencat 2019).

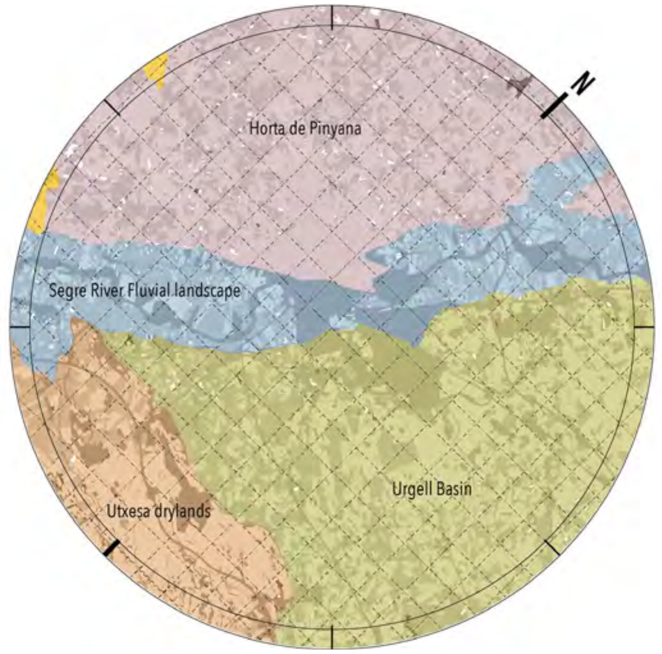


Figure 5.19: Landscape units. (Observatori del Paisatge 2006, Land use: ICC).

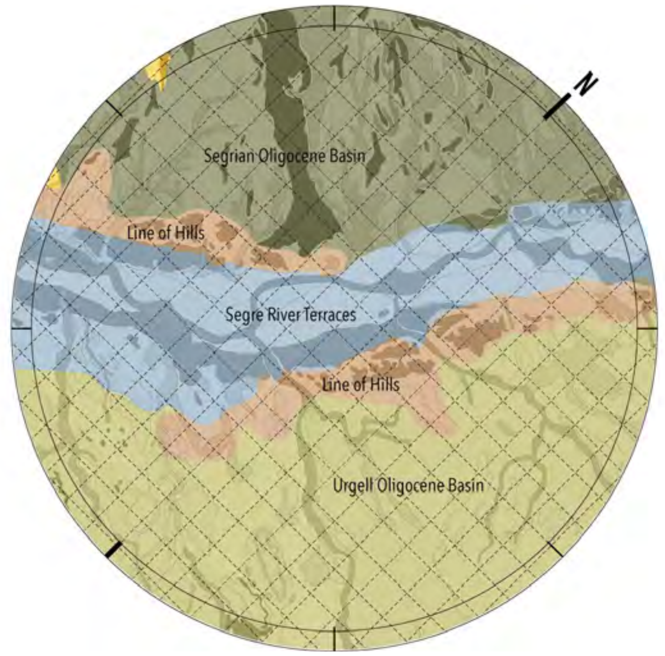


Figure 5.20: Geomorphological Landscape Units over geomorphological map. (Aldomà 2012; Instituto Tecnológico Geominero de España1998).

The need to actualise these, among other contradictions, drove the Municipality to make a new plan, the PG18 here or POUM, presented in 2018 but not approved. A broader approach to protections included additional elements in the designated areas with special protections (Poum Lleida 2018). However, these protections were mainly passive, preventing urban development without actively regenerating or restoring any damage. Still, 'Landscape Units', part of the catalogue of Landscapes, were also named under the PG18 to ensure coherence across the larger supra-municipal context (Poum Lleida 2018:123).

The Catalogue of Landscapes describes the socio-cultural aspects, which are classified into units based on geomorphology, land uses, historical organisation, perception of landscape, and the relationship between geography and inhabitants (Observatori del Paisatge 2010). The municipality of Lleida covers three of these landscape units (See Figure 5.19) (Observatori del Paisatge 2006). However, these differentiations do not have any follow-up in strategies.

On the other hand, the local researcher Ignasi Aldomà's study (2012) made an accurate distinction among the agroclimatic characteristics of the territory (Figure 5.20), which, even if it was previous to the PG18, was not considered. However, it is relevant for this work and other ecological approaches because it considers geological and climatic aspects. The Segre River Terraces with more fertile land and thermal inversion, the 'line of inhospitable Hills' by the River terraces, the **Segrian Oligocene Basin**, and the **Urgell Oligocene Basin** are four central regions. Differing between the Segrian and the Urgell Basins, the second one has a top layer of graves that aids drainage, allowing a more dispersed water distribution through ditches. This distinction shows how geological formations impact agricultural practices, a local knowledge often overlooked in planning; for instance, there is more risk for frost on the river terraces than at higher altitudes, so there we can find more pears than peaches (Aldomà Buixadé 2012).

CASE STUDY

5.3 ECOSYSTEM CHARACTERISATION AND SPATIAL DISTRIBUTION: MAPPING NATURAL HABITATS AND URBAN BIODIVERSITY.

The "Map of Potential Vegetation of Catalonia" identifies critical habitats and provides valuable geographical distribution information for the **Carrasca Forest, Maquis Shrubland, Inland Salt Steppe, and Riparian Forest** (Carrillo et al. 2019). These are recognised as potential habitats of the region and coincide with the descriptions of Landscape Units (2006) and Panareda (2011). *Appendix H: Existing Habitat Characterisation* contains information about the characteristics of each of these habitats.

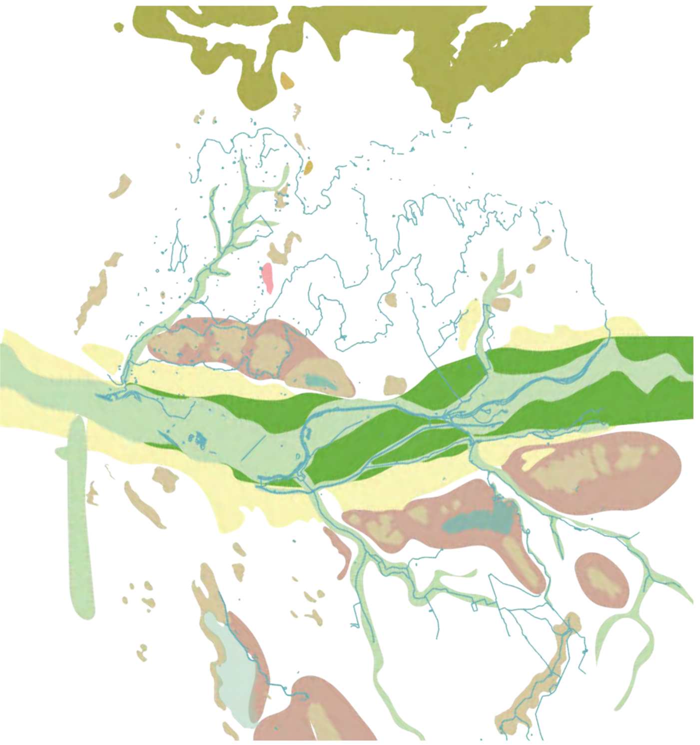


Figure 5.21: Grouped habitat distribution diagram with water separating water habitats with hills following the geological patterns of the territory (Instituto Tecnológico Geominero de España1998).

However, Carrillo et al.'s (2019) work lacks finer detail regarding topographical and microclimatic variations in this region—such as differences between hills, slopes, and flat areas—essential factors highlighted by Panareda (2011) and Aldomà (2012). On the other hand, the habitats of communitarian interest [HIC] present in the territory showed a higher variation of habitats (Vigo et al. 2006; Carreras et al. 2015, 2016; Aymerich et al. 2016; Ferré Codina et al. 2018), similar to the revised version of the cartography of Catalan habitats (GEOVEG 2018). Figure 5.21 partially illustrates the overlaying of habitats, while Figure 5.22 groups the habitats according to water and hills.

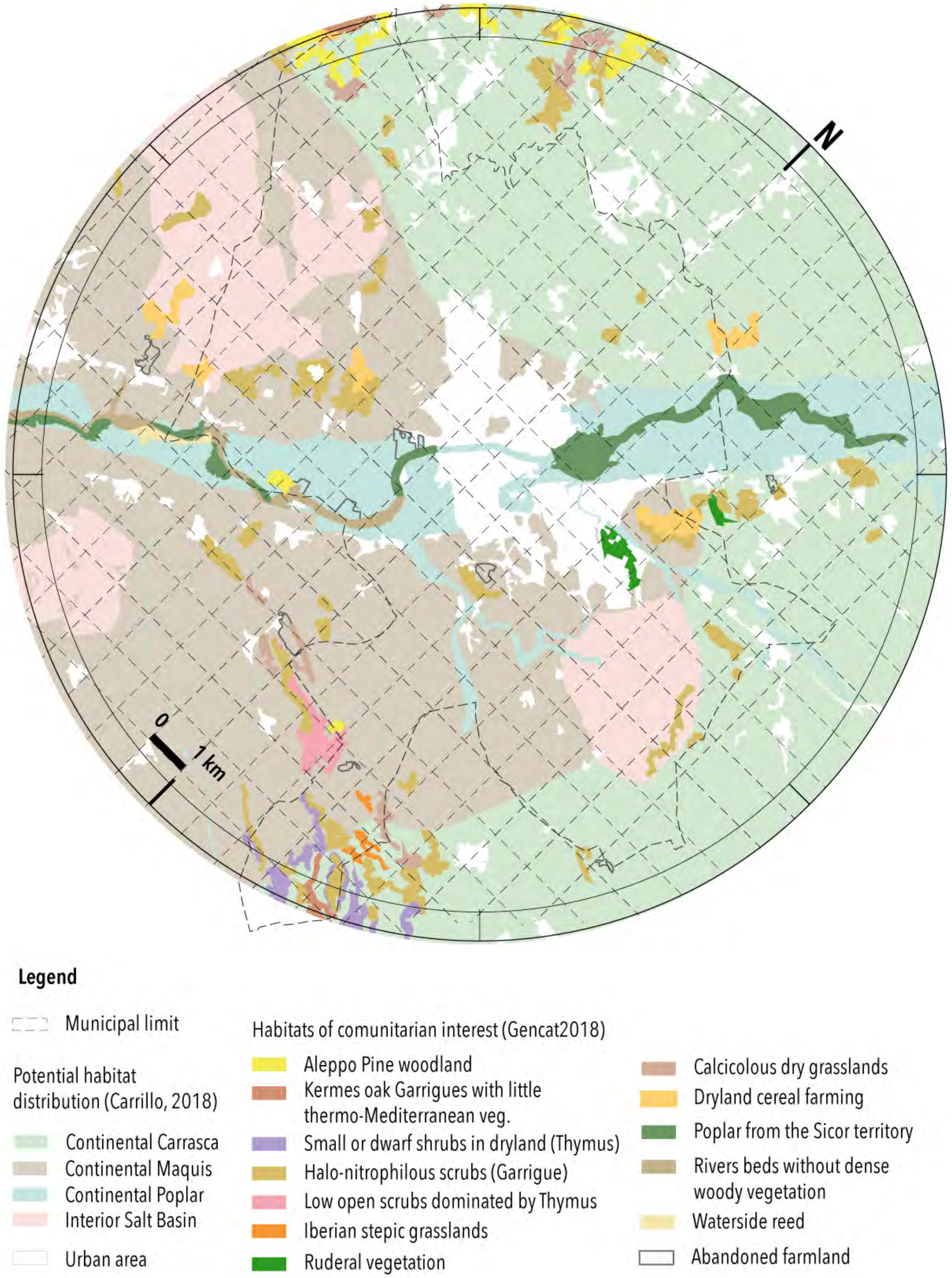


Figure 5.20: Graphic comparison between potential vegetation distribution and Catalan Habitat distribution. (Carrillo et al. 2019; GEOVEG 2018).

Figure 6.2: Mixed pattern of bloomed peach trees and cereal crops with some olive trees on the terraces. The photo was taken from Serra Llarga, northwest of the city. March 2023.

CHAPTER

6

ANALYSIS OF THE POTENTIALITIES. UNLOCKING LLEIDA'S POTENTIAL FOR A COOLING ISLAND NETWORK

6.1 PATCH IDENTIFICATION AND CHARACTERISATION.

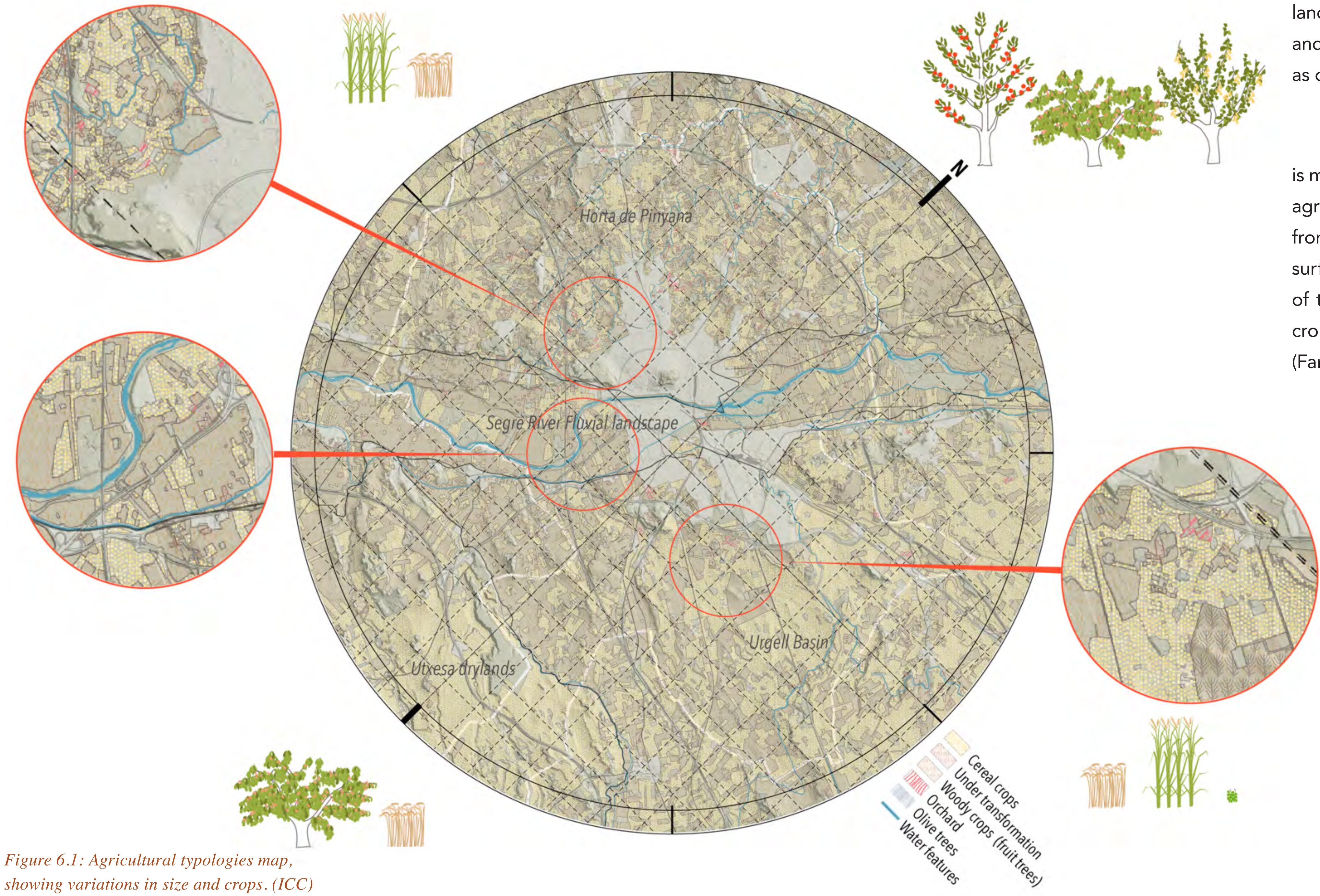


Figure 6.1: Agricultural typologies map, showing variations in size and crops. (ICC)

6.1.1 Agricultural and Landscape Units: The Role of Crops in Cooling Dynamics

The size and type of crops vary around the city, with prominent intensive agriculture surrounding the urban area, as shown in Figure 6.1. A more extensive grain is found in the eastern part with prominent herbaceous crops, and in the southern part of the landscape unit, predominate woody crops. In the western region, the grain is smaller. The proportion of woodland cultivated in the fluvial landscape unit is higher because of its ideal conditions (Aldomà Buixadé 2012), and poplar trees are also grown here for their wood. Other kinds of farming, such as orchards of olive tree planting, are reduced to exceptionalities in the territory.

According to Aldomà (2012), the *horta* transformation -the closer surroundings- is more connected to the city and its inhabitants' needs than expanding intensive agriculture. The same author also discusses how land transformation is shifting from fruit trees to annual crops, and thus, a need exists to increase the land surfaces to make them more rentable (Aldomà Buixadé 2012). The consequences of this transformation go against ecological improvement since the number of crop edges, which are resting places for a broad range of biodiversity and habitat (Fanlo 2023), declines and biodiversity decreases.

Figures 6.3-6.5 (left, middle, and right): (6.3) Fruit tree crop prepared to be planted in October 2022. (6.4) Fruit trees irrigated by inundation in la Bordeta. Inundation is still a traditional system using water from the canal. (6.5) Bloomed peach tree at the end of March 2023.

6.1.2 Natural and Semi-Natural Patches: Green Fragments in an Urban Fabric

Groups of denser canopies are scarce and scattered; while some are within urban green zones, most remain isolated. Figure 6.6 also shows a more extended distribution of bushland that follows the topography.

The most prominent features are related to the Segre River, but even the river is fragmented. The river's canalisation is a barrier between the downriver and the ecosystems from the north when passing by the city. *La Mitjana Park* is the most extensive mass in the region. It is located at the beginning of the *Segre River* Canalisation, which is unfavourable regarding cooling breeze distribution during summer: it either blows away the urban area or is canalised through the river canalisation. From a resilient strategy perspective, this park remains alone and unique within the municipality, which puts excessive pressure on the habitat.

Urban green areas [UG] distribution coincides with the wealthier zones, such as *Ciutat Jardi*, and other protected zones, such as the main roads. Even if the good sake of the infrastructure is relevant for society, it has very little to do with citizens' health, which, according to the WHO, UG might *"serve as a health-promoting setting for all members of an urban community"* (WHO 2020:2).

Figure 6.7: (left) Southern part of Segre River, just after the urban canalisation.

CASE STUDY - ANALYSIS POTENTIALITIES

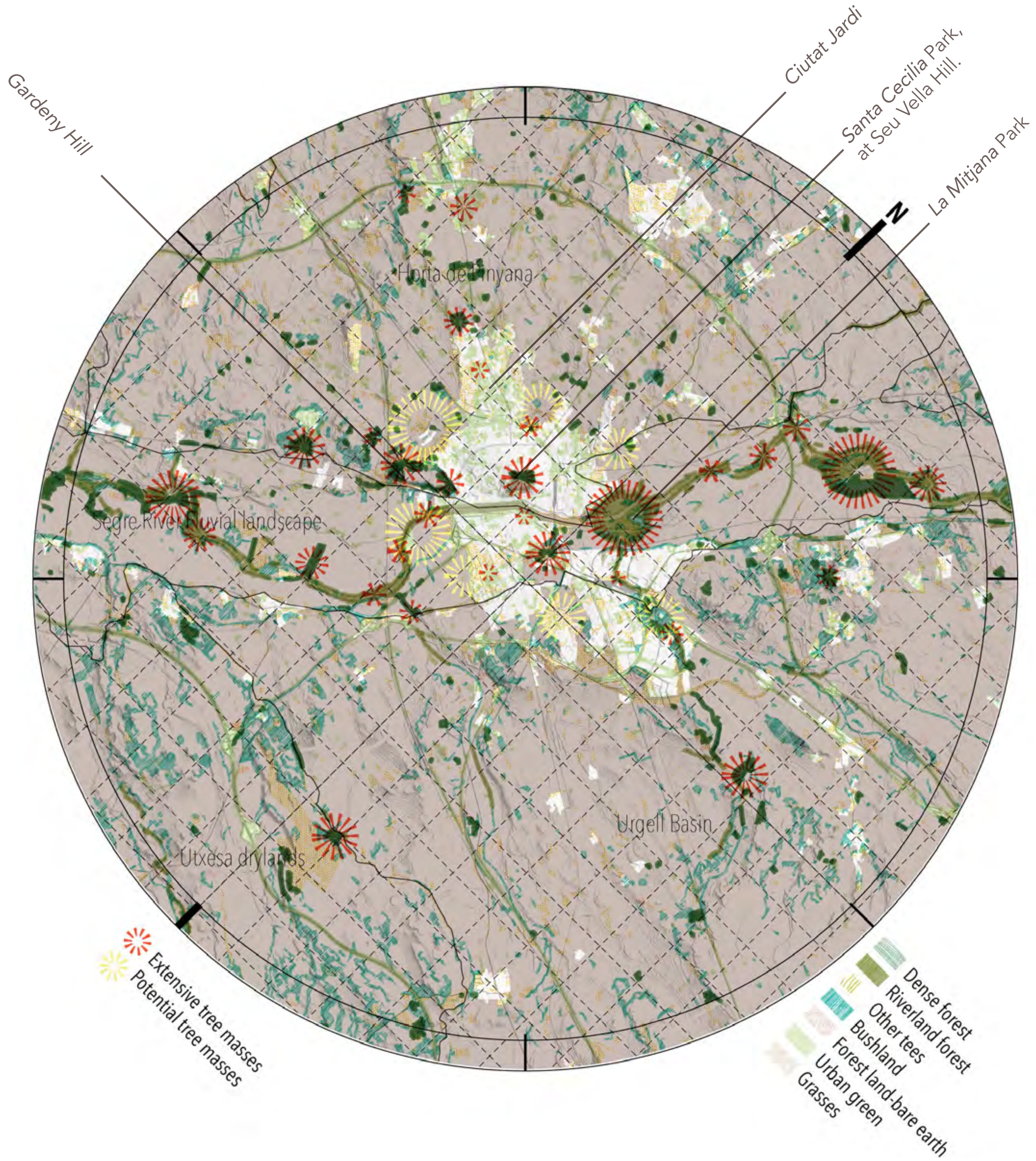


Figure 6.6: Map of existing natural and semi-natural patches. (ICC).

6.1.3 *Urban Free Spaces: Distribution, Accessibility, and Potential.*

According to the PG99, Lleida has various parks with differing classifications, as seen in Figure 6.9. Of the seven urban parks, two are not accessible to the public -*Vallcalent* and *Arboretum*-and the two hills, *Gardeny* and *Seu Vella*, are characterised by inaccessible prominent slopes and historical heritage remnants with extensive parking areas. *Magnolia* Park, with a particular triangular shape, has a vast canopy of trees that give it its name. On the other side of the river, *Camps Elisis* is one of the most multi-used parks since many city events happen there. *Les Aigües* Park is a new one connected to the Major Canal, and the Polygon Park is a protected area at the edge of the Industrial Polygon with very unclear accessibility since it is a suburban position surrounded by roads and massive buildings.

The distribution and function associated with squares, green spaces, and linear free spaces are more related to neighbourhoods, but there is still no systematic pattern. Notably, green space density is missing from denser areas.

Overall, the distribution of UFS lacks connectivity between them and other environmental features, which opposes the resilience principles (Ahern 2011). Likewise, the exclusivity of functions is very present in how UFS are conceived. For instance, *La Mitjana* Park currently provides supportive ES, *Gardeny* and *Seu Vella*, mostly cultural ES, and the Segre River Canalisation focused on recreation (See Figure 6.8). Moreover, areas with a complete absence of UFS, such as the industrial area in the east part of Lleida, are remarkable, or the presence of parking lots with considerable size and distribution indicates a lack but also an opportunity for a denser and more homogenous network.

Figure 6.8: (left) Foto of Segre River Canalisation with users and equipment.

Figure 6.9: (right) Map of urban free spaces. It combines the municipal classification with added playgrounds and parking lots. (Ajuntament de Lleida, 2022; Google Earth).

CASE STUDY - ANALYSIS POTENTIALITIES

6.2 ASSESSING HEAT IMPACT ACROSS LLEIDA'S LANDSCAPE

6.2.1 *Heat Map Insights: Identifying Thermal Hotspots and Cool Zones*

The heat map reveals a variation of 13°C between areas. Figure 6.10 illustrates the land surface temperature [LST] difference between regions, with a blurred delineation between urban and rural in the Horta de Pinyana unit and a sharper contrast in the Urgell Basin unit.

Figure 6.12: Close-ups from the LST with heating areas. A-De les Arts Park, B-Interstitial Plot, C-Sport facility, D-New Planting at Gardeny Hill, E-Extensive agriculture, F-Torres Salses Development, and H-Agriculture field with clear irrigation traces. (Landsat)

The extensive roofs in the industrial area increase heat, as shown in Figure 6.10 and detail G in Figure 6.12. In the east, the abandoned plots of the Torres Salses development have high temperatures (See F-detail in Figure 6.12). Finally, even if the Natural Reserve Mas-de-Melons remains somewhat separated from the urban area, its high temperature compared to the region is essential to note. Even if it has specific protection, most of the area includes agricultural practices from dryland, making it unclear whether the use, practice or typology of rugosity conditionate these observations.

Figure 6.13: Close-ups from the LST with cooling areas. a-Mitjana Park, b-Segre River Canalisation, c- Santa Cecilia Park, d-Humbert Torres Square, e-Football field, f- Rural area at Vallcalent, and g-Irrigated crop. (Landsat)

Conversely, areas related to water features consistently demonstrated cooler temperatures, such as the Segre River Canalization, the wetland park (b-detail and h-detail, respectively, in Figure 6.13), and La Mitjana Park (a-detail, Figure 6.13), which recorded the lowest temperatures thanks to its dense tree cover and water elements. Irrigated lawns, such as the Raïmat Golf Club, Segre River Canalisation, or the football field in detail-e in the exact figure, also benefited from temperature

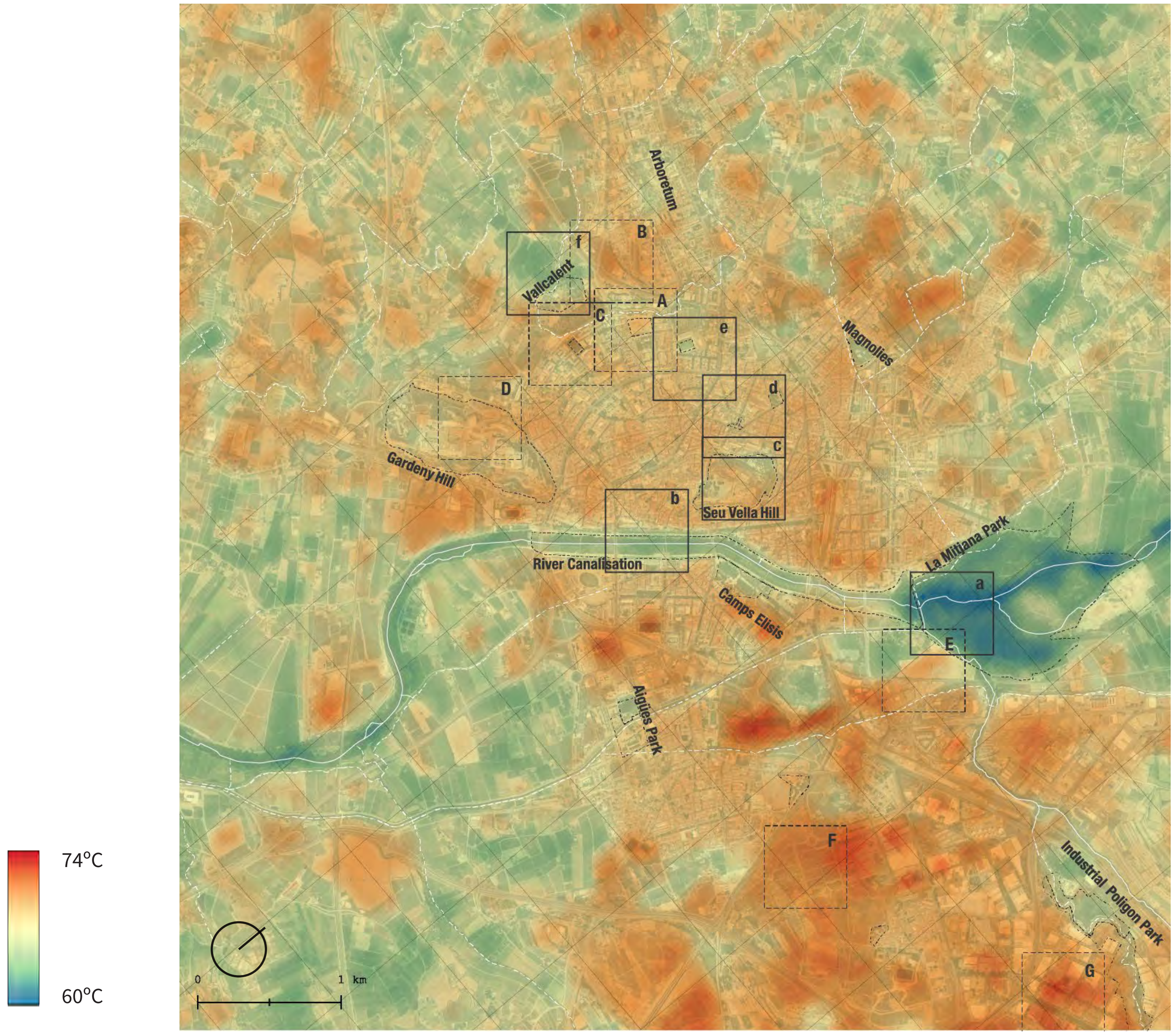


Figure 6.10: Land Surface Temperature Map, June 24, 2022. (Landsat) Chapter 2 and Appendix B: LST Calculation describes the considerations and calculations to achieve this map.

reductions. This observation coincides with the observations done by Shashua-Bar et al. (2010). Tree-dominated areas like Les Magnolies Park, Humbert-Torres Square (d-detail), and the shaded northern slope of Seu Vella Hill (c-detail) showed strong cooling responses.

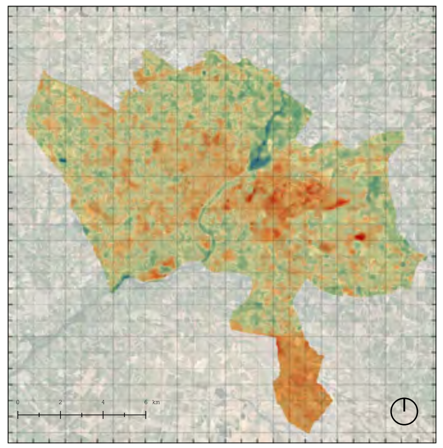


Figure 6.11: Heat map at the municipality scale. At this scale, it is easy to appreciate the contrast between industrial and urban areas. Also, the drylands on the lower part of the image correspond to the nature reserve of Mas-de-Melons.

6.3 COOLING ISLANDS IN DETAIL.

The map of Lleida's existing cooling islands (Figure 6.13) illustrates a fragmented and spatially disconnected network. Urban cooling patches include UFS and other areas. They are generally small, with distances exceeding 600 metres between them, which offers a limited cooling capacity at the city scale. Except for the most extensive area but not effectively propagating horizontal cooling, La Mitjana Park is situated precisely where winds cannot move their breeze horizontally across the urban area, as it either expands towards the nearby rural area or can exceptionally be channelled through the river without impacting the city. Eight spaces are studied closely to understand more of these cooling islands' functions.

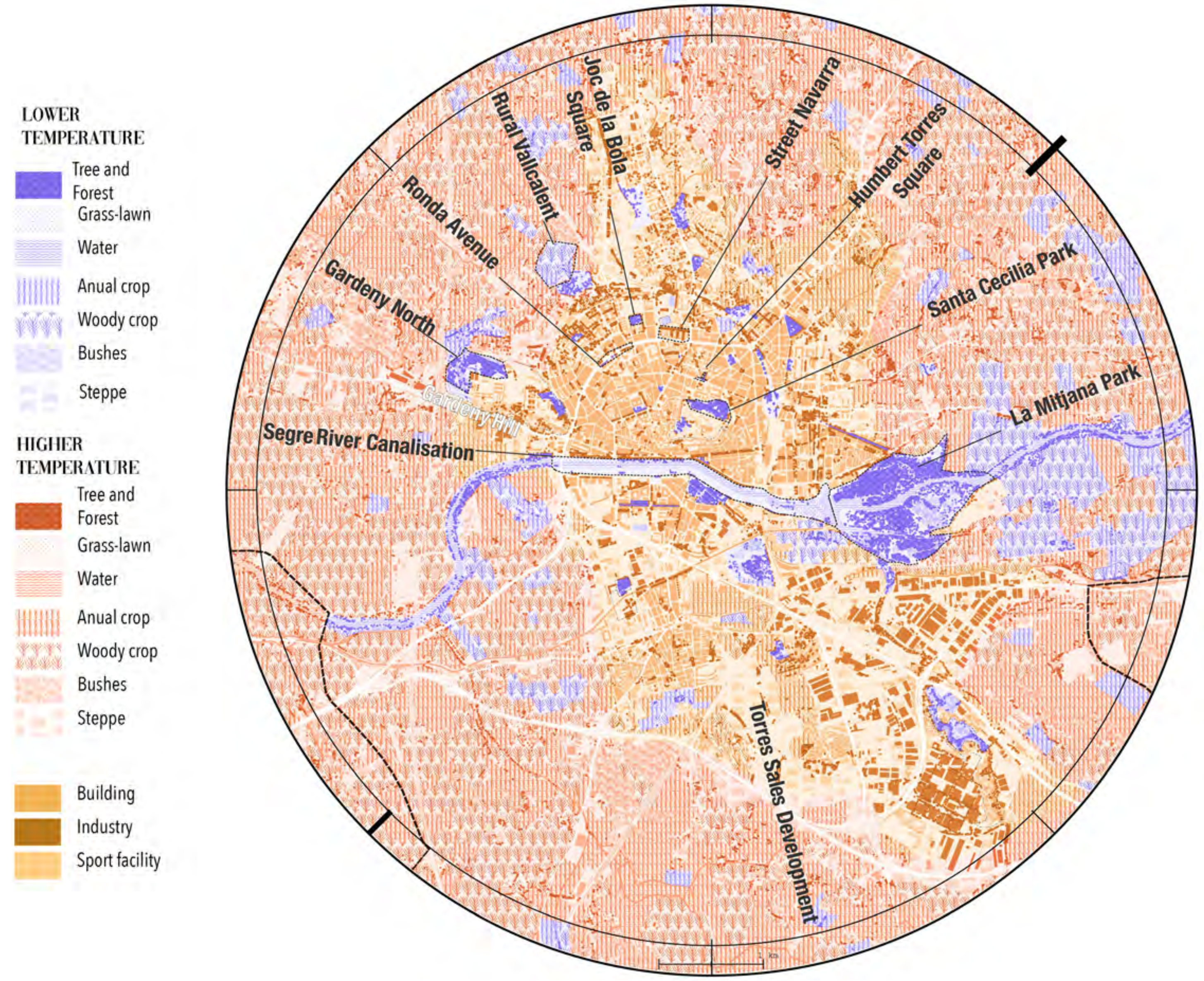


Figure 6.14: Map of existing patches of cooling islands based on LST and areas further explored.

6.3.1 *Closer Analysis to eight Key Cooling Areas*

Using a tool to guide the analysis helped me examine the critical variables composing each patch and their combination, such as tree density, age, species variation, interaction with water elements, and soil formation, among others (See Appendix E: Ecosystem Services and ESTER 2.0 to see the variables considered). While the tool may not be very accurate owing to the study's limitations, it still offers an intriguing approach to its potential and valuable results, which are summarised in Table 6.1.

The results provide an interesting comparison between the areas shown in Table 6.1 and Figures 6.15 to 6.38, which can be summarised as follows.

While all of them show considerable regulating capacity due to the presence of trees, their role in regulating local climate and extreme events is not very clear since there is not a wide variety of species that can adapt to a broader variety of extreme situations. Moreover, the conjunction of vegetation and water features that considerably reduce the local climate only exists in La Mitjana Park. The absence of water management is a significant aspect lacking in most areas. Except for the streets, all have a critical cultural role more supported by historical aspects than actual natural and recreational ones.

Table 6.1: Ecosystem services result comparison between the eight close-up studied areas.

Ecosystem Services	Mitjana Park	Segre River Canalisation	Seu Vella Hill	Gardeny Hill Nort	Humbert Torres Square	Joc de la Bola Square	Navarra Street	Abandoned land Partida Mariola
Biodiversity	74,5%	45,1%	25,5%	41,2%	21,6%	27,5%	23,5%	43,1%
Ecological interaction	66,7%	33,3%	33,3%	41,2%	33,3%	66,7%	0,0%	22,2%
Habitats for especies	83,3%	66,7%	66,7%	39,2%	0,0%	50,0%	0,0%	33,3%
Natural cycle	90,5%	38,1%	19,0%	37,3%	9,5%	14,3%	14,3%	38,1%
Soil formation	100,0%	100,0%	66,7%	66,7%	0,0%	0,0%	0,0%	100,0%
Local climate	83,3%	44,4%	27,8%	45,1%	22,2%	66,7%	22,2%	55,6%
Erosion prevention	66,7%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%
Protection extreme events	66,7%	33,3%	0,0%	33,3%	0,0%	0,0%	0,0%	0,0%
Air cleaning	100,0%	0,0%	33,3%	33,3%	33,3%	33,3%	0,0%	0,0%
Sound regulation	66,7%	0,0%	0,0%	0,0%	66,7%	66,7%	0,0%	0,0%
Regulation and cleaning of water	100,0%	33,3%	33,3%	33,3%	0,0%	33,3%	0,0%	33,3%
Pollinisation	66,7%	44,4%	44,4%	22,2%	11,1%	33,3%	33,3%	66,7%
Biological control	33,3%	33,3%	33,3%	33,3%	0,0%	0,0%	0,0%	100,0%
Food	33,3%	20,0%	0,0%	0,0%	0,0%	0,0%	13,3%	66,7%
Fresh water	66,7%	33,3%	0,0%	5,6%	0,0%	0,0%	0,0%	16,7%
Raw materials	16,7%	0,0%	16,7%	16,7%	0,0%	0,0%	0,0%	50,0%
Energi	16,7%	16,7%	16,7%	16,7%	16,7%	0,0%	0,0%	27,8%
Recreation and physical health	72,2%	63,9%	44,4%	55,6%	69,4%	75,0%	41,7%	80,6%
Mental well-being	76,7%	30,0%	40,0%	60,0%	30,0%	33,3%	40,0%	60,0%
Aesthetic apreciation	73,3%	46,7%	26,7%	33,3%	40,0%	60,0%	20,0%	20,0%
Social interaction	100,0%	66,7%	100,0%	66,7%	50,0%	50,0%	0,0%	50,0%
Cultur heritage and identity	50,0%	50,0%	100,0%	100,0%	0,0%	0,0%	0,0%	16,7%

La Mitjana Park

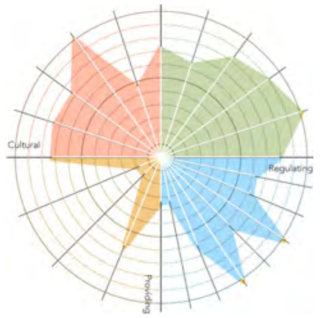


Figure 6.15: Radial chart of la Mitjana Park ecosystem services.

Figure 6.16: Picture of tree density and biological stratus at La Mitjana Park. Photo taken under exploration no. 6.

Figure 6.17: Orthophoto of a detail of the area corresponding to detail-a of Figure 6.13.

Segre River Canalisation

Figure 6.18: Radial chart of Segre River Canalisation's ecosystem services.

Figure 6.19: Lawn and trees at Segre River Canalisation. Photo taken under exploration no. 6.

Figure 6.20: Orthophoto of a detail of the area corresponding to detail-b of Figure 6.13.

Santa Cecilia Park

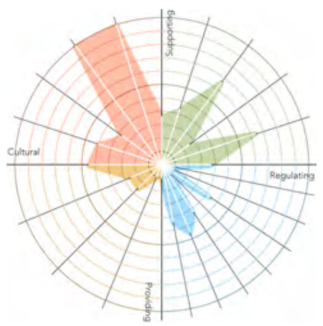


Figure 6.21: Radial chart of Santa Cecilia Park's ecosystem services.

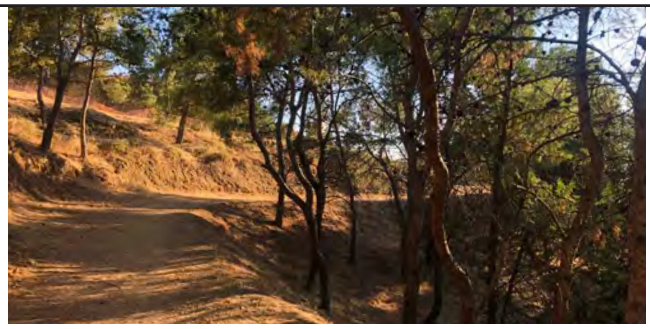


Figure 6.22: Aleppo pine trees from Santa Cecilia Park, north of Seu Vella Hill. Photo taken under exploration no. 4.

Figure 6.23: Orthophoto of a detail of the area corresponding to detail-b of Figure 6.13.

Gardeny North

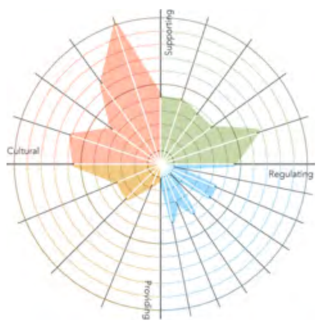


Figure 6.24: Radial chart of Gardeny Hill's ecosystem services.

Figure 6.25: Clearance of pines and paths at the north edge of Gardeny Hill. Photo taken under exploration no. 3.

Figure 6.26: Orthophoto of a detail of the area corresponding to detail-c of Figure 6.13.

Humbert Torres Square

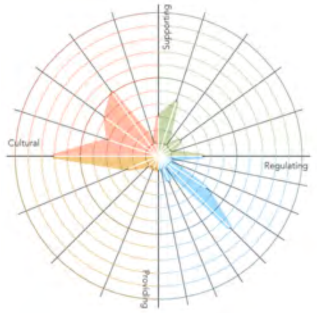


Figure 6.27: Radial chart of Humbert Torres Square's ecosystem services.

Figure 6.28: Canopy cover at Humbert Torres Square (Google view). Corresponding to exploration no. 1.

Figure 6.29: Orthophoto of a detail of the area corresponding to detail-d of Figure 6.13.

Joc de la Bola Square

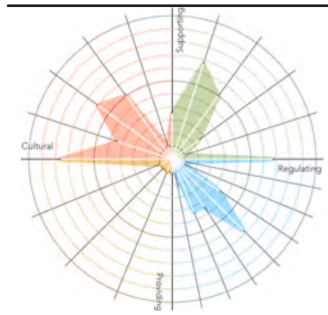


Figure 6.30: Radial chart of Joc de la Bola Square's ecosystem services.

Figure 6.31: Light and shade at Joc de la Bola Square. Photo taken under exploration no. 1.

Figure 6.32: Orthophoto of a detail of the area.

Street Navarra

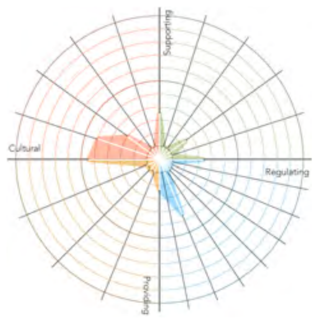


Figure 6.33: Radial chart of Street Navarra's ecosystem services.

Figure 6.34: Canopy cover from Street Navarra (Google view). Corresponding to exploration no. 1.

Figure 6.35: Orthophoto of a detail of the area corresponding to detail-b of Figure 6.13.

Rural Area in Vallcalent - Mariola

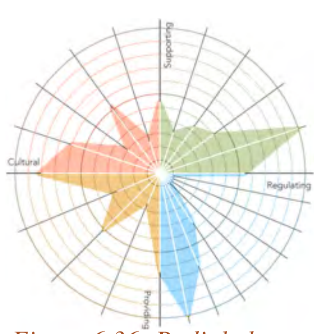


Figure 6.36: Radial chart of rural area of Vallcalent ecosystem services.

Figure 6.37: Topography and vegetation variety in the rural area of Vallcalent, with the fenced Fauna de Vallcalent at the end. Photo taken under exploration no. 3.

Figure 6.38: Orthophoto of a detail of the area corresponding to detail-f of Figure 6.13.

6.4 DESIGNING HEAT-RESILIENT HABITATS FOR LLEIDA..

6.4.1 Habitat Distribution: Integrating Geomorphology and Topographical Variability

Habitat distribution varies with geomorphology and topography, reflecting the influence of soil conditions on microclimate. Figure 6.39 proposes a general distribution of natural habitats considering the geomorphological characteristics of the region. Due to soil and hydraulic protections, the differentiation between river sides associated with different landscape units (Observatori del Paisatge 2006) is also identified here. The variation between the more exposed tops of the hills and the protected lower areas (Panareda 2011) requires a detailed scale study, which is superficially approached in Figure 6.40. Likewise, there is probably a difference between the hills' south and north sides that might be relevant to further studies on accurate vegetation selection.

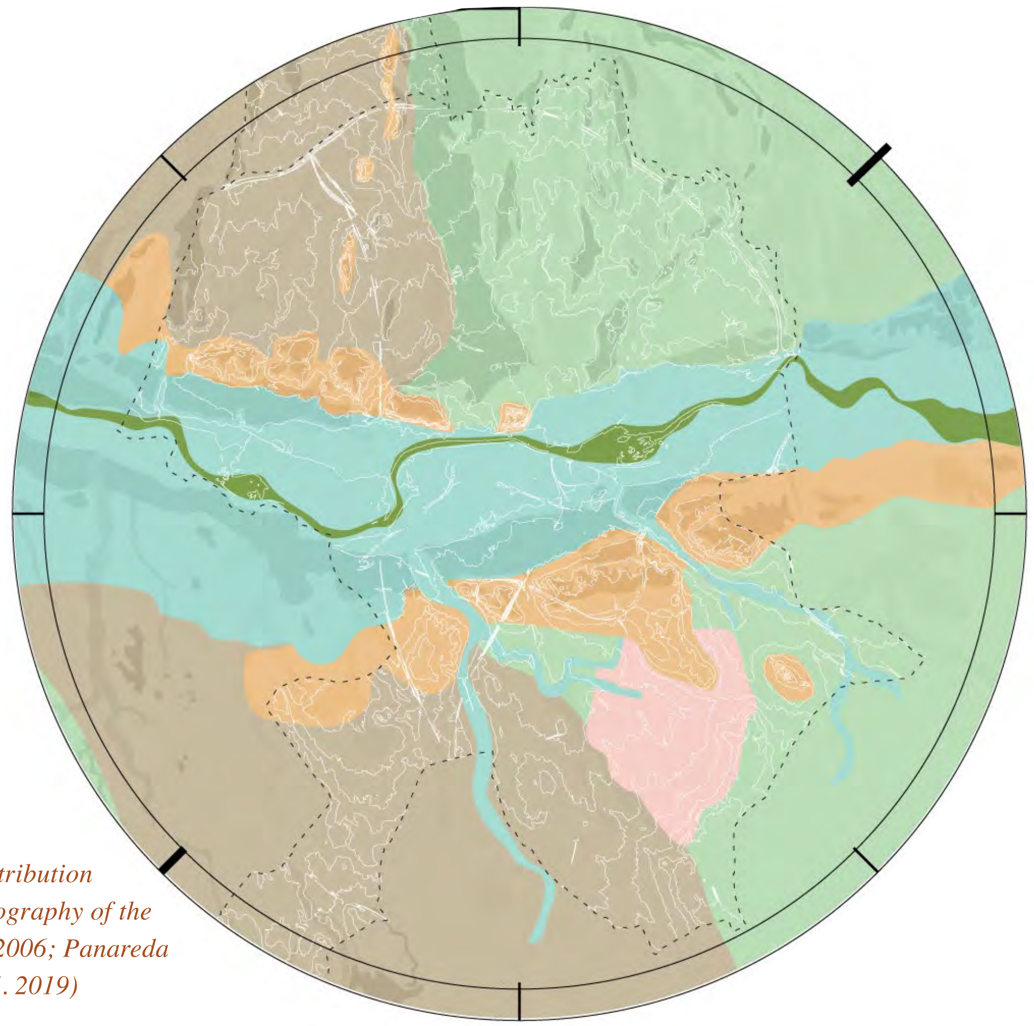


Figure 6.39: Potential ecosystem distribution considering geomorphology and topography of the territory. (Observatori del Paisatge 2006; Panareda 2011; Aldomà 2012: 1; Carrillo et al. 2019)

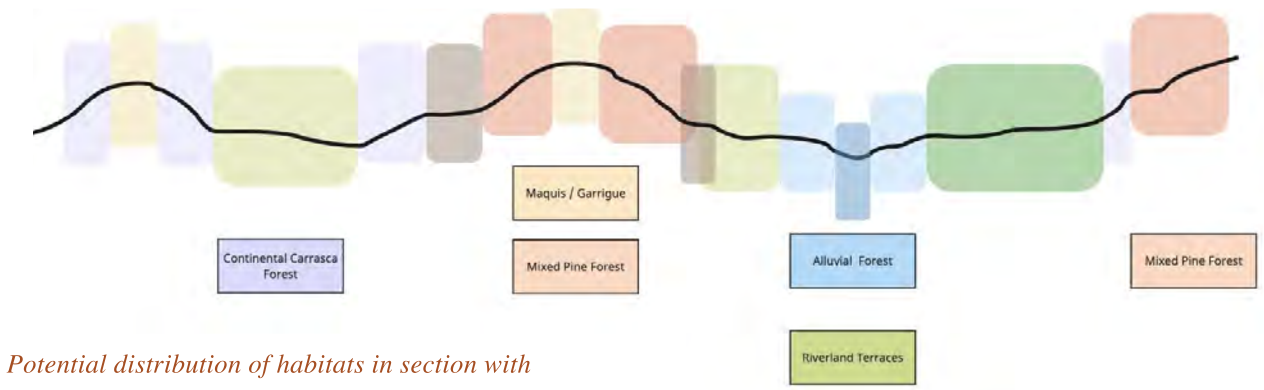


Figure 6.40: Potential distribution of habitats in section with degradation states. Modified from source. (Panareda, 2012: 15).

Since tree-dominated areas significantly impact local climate regulation, the selection of referent habitats for ecological rehabilitation must incorporate versions of habitats containing trees for the Continental Maquia, Garrigue, and salt steppe basin that can coexist when these regions encounter urban stressing factors.

Therefore, the tree-dominated habitats present in the region are proposed as prime foundational habitats based on the area's existing habitats: the riparian forest, the Carrasca Forest, and the Mixed Pine Forest (see Appendix I: Existing Habitats Characterisation for a description of each habitat). These contain the structural components for Lleida's three potential heat-resilient habitats, including their sub-climax habitats provided by perturbations, such as maquis, pine forests without underground, and steppe, as shown in Figure 6.41.

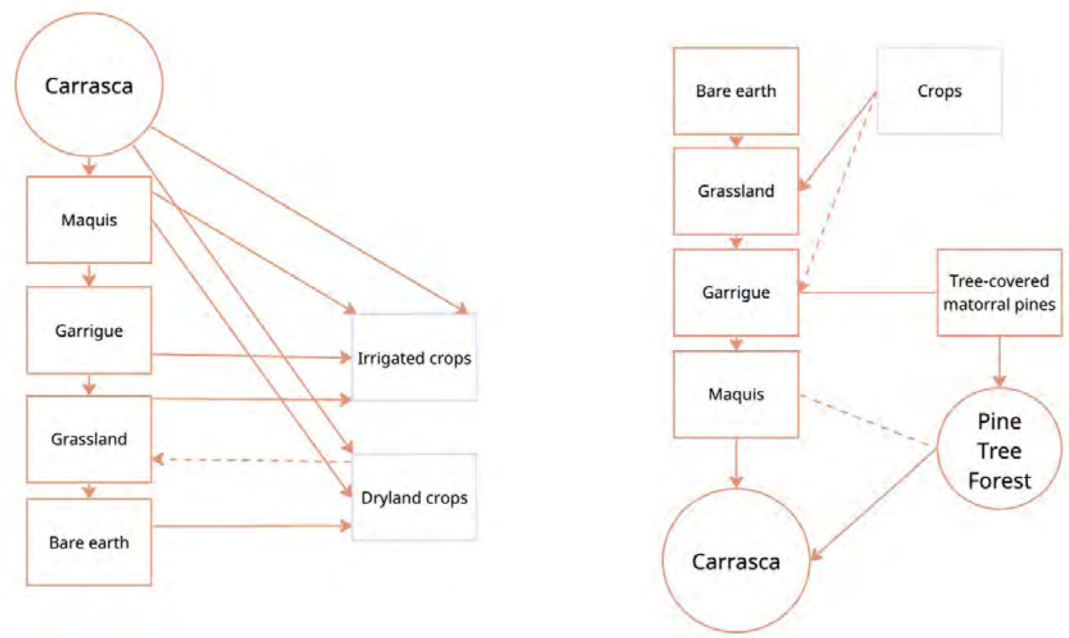


Figure 6.41: Diagram of ecosystems' degradation patterns on the left and progressive evolution on the right, based on Tomaselli (1977) and modified from source. (Tomaselli, 1977: 359).

CASE STUDY - ANALYSIS POTENTIALITIES

6.5 BUILDING A RESILIENT COOLING NETWORK: CHALLENGES AND STRATEGIES FOR LLEIDA

The analysis of Lleida's cooling island network highlights a fragmented system with compromised resilience. Three types of cooling patches—agricultural units, natural patches, and urban free spaces—contribute to temperature regulation but face critical challenges.

Agricultural areas provide cooling through evapotranspiration, but intensive farming and crop transformation reduce biodiversity and resilience. While irrigation helps mitigate heat, the long-term viability of water use is uncertain. In turn, natural patches, such as the Segre River and La Mitjana Park, offer cooling benefits, but their impact is weakened by spatial fragmentation and unfavorable wind patterns. Their uniqueness contradicts the redundancy resilience principle. Finally, urban free spaces (UFS) are unevenly distributed, with areas lacking accessible green spaces and limited connectivity between UFS contradicting resilience principles.

Heat mapping reveals temperature differences of up to 13°C, with industrial zones and drylands being the hottest. Water features and tree-dense areas offer the most effective cooling, but agricultural irrigation complicates land surface temperature interpretations.

Like UFS distribution, cooling islands remain disconnected, reducing their overall efficiency. Most are too small and too far apart to create a cohesive cooling effect. Additionally, the lack of species diversity and water management hinders long-term climate adaptation.

In conclusion, integrating natural elements, expanding tree-dominated habitats, and enhancing connectivity between cooling patches are essential to improving resilience. Moreover, the replicability of the functions that La Mitjana Park provides, but on the other edge of the city so that the city could benefit from the horizontal cooling patterns, would respond to the system's resilience improvement. Finally, strategically placed small-scale interventions supported by other strategies to reduce heat emission from the major hotspots in the urban area could create a cumulative cooling effect, fostering urban heat resilience.

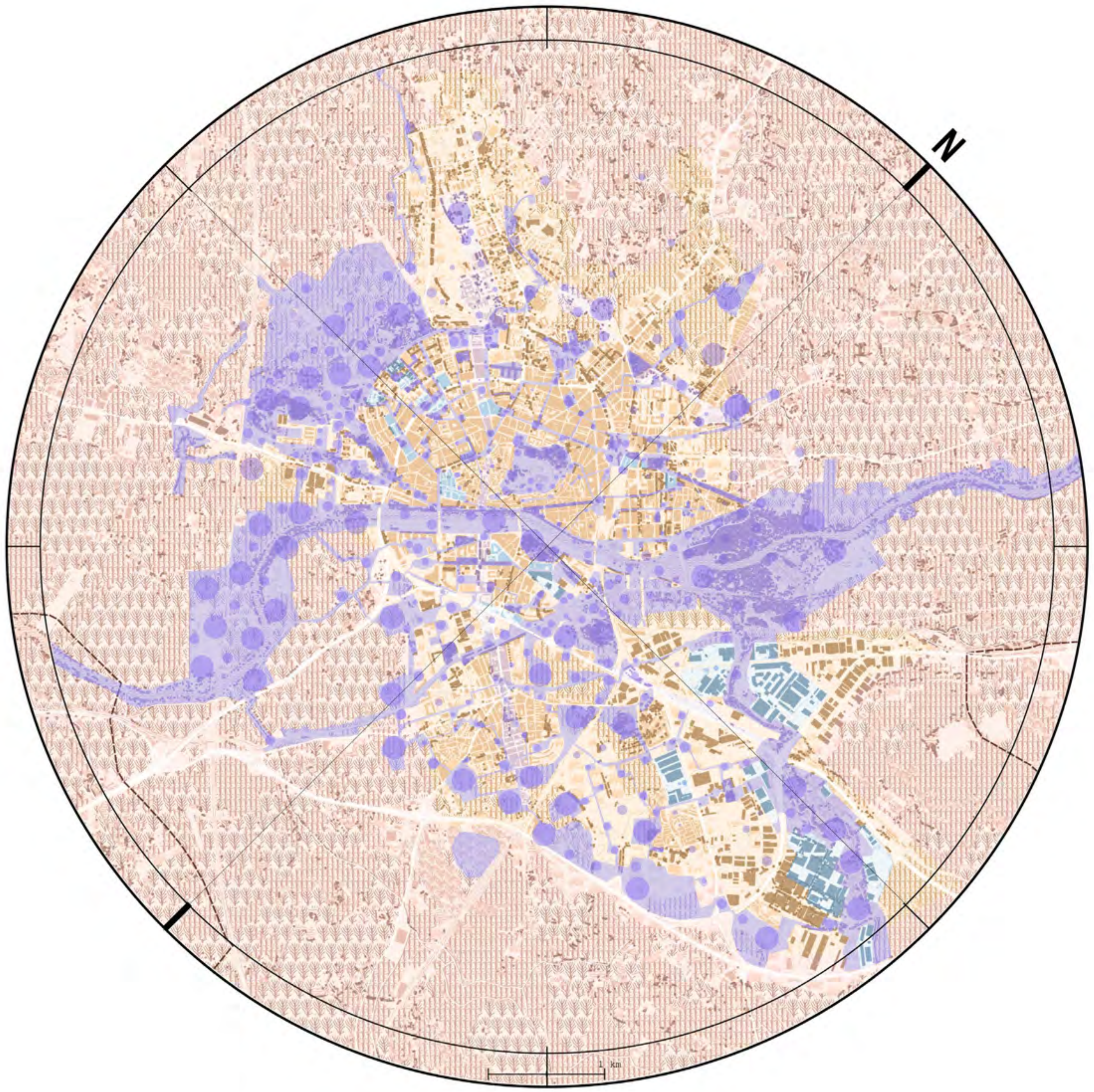


Figure 7.1: Proposal for an interconnected cooling island network at a municipal scale. It includes existing and proposed cooling islands, interconnecting them with site logic.

CHAPTER

7

EXPLORATORY IMPLEMENTATION OF REHABILITATIVE COOLING NETWORK IN LLEIDA.

A future vision of Lleida would include an interconnected network of healthy ecosystems designed and maintained as cooling islands (Figure 7.1). At the municipal scale, two new parks of comparable size to La Mitjana are proposed in the western and southwestern parts of the city. Taking advantage of the available space on the edges, these two areas could be crucial to generating cooling breezes for the city while creating a barrier from warmer winds from this direction.

This vision is treated here as a guide to starting a dynamic regenerative process. For this reason, it is critical to recognise and understand this proposal's **immutable factors and components—the invariable variables of this rehabilitative toolkit**.

7.1 KEY INSIGHTS FROM THE EXPERIMENTAL STUDY

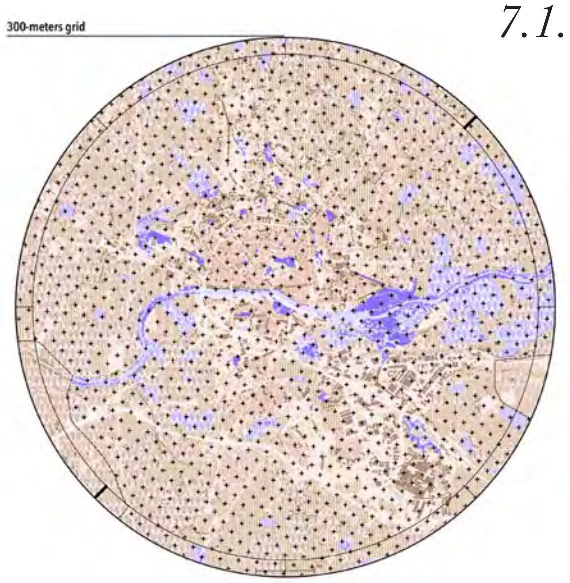


Figure 7.2: 300-meter grid over the existing cooling island distribution map.

7.1.1 Mapping Opportunities: Identifying Strategic Spaces for Intervention

When approaching the network creation, a group of priorities was considered. First, available urban and close rural spaces were identified following a grid 300 metres apart (Figure 7.2). Surfaces bigger than 200 sqm were allowed, and southern and western positions concerning canon streets were prioritised. From there, various scenarios emerged according to land use and the existing conditions of morphology, materiality, and available space variations, as illustrated in Figures 7.3 and 7.4.

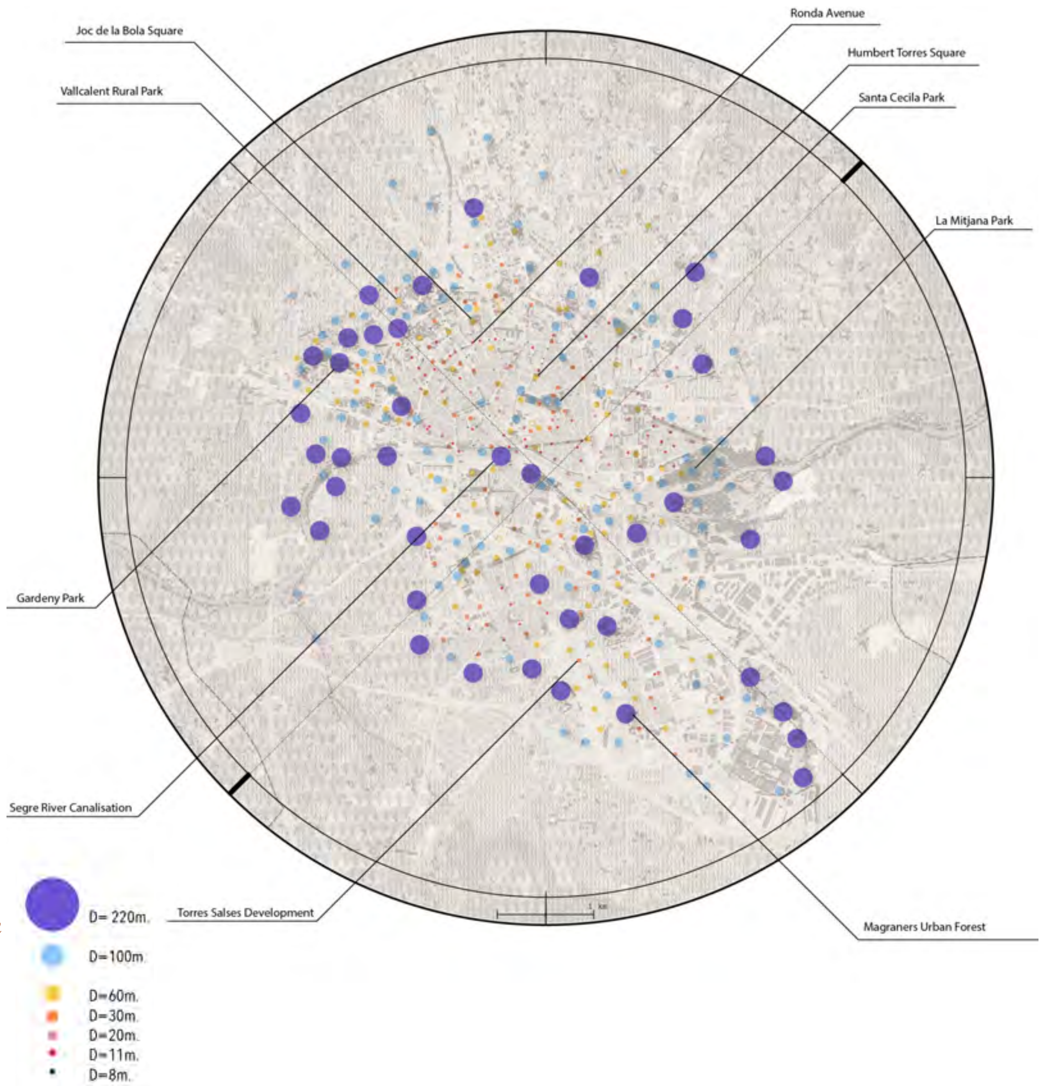


Figure 7.3: Potential patch interventions with size variabilities. Circles of diameters between 18m to 220m represent potential cooling islands, while 8m and 11m diameter refer to 'stepping stones'. The sizes have already been adapted to the existing situation. For instance, in La Mitjana Park, significant interventions to improve its cooling capacity might not be necessary. However, minor supporting interventions that add functions such as natural playgrounds or other recreational spots to rest and enjoy the ecosystem services it provides might still be interesting.

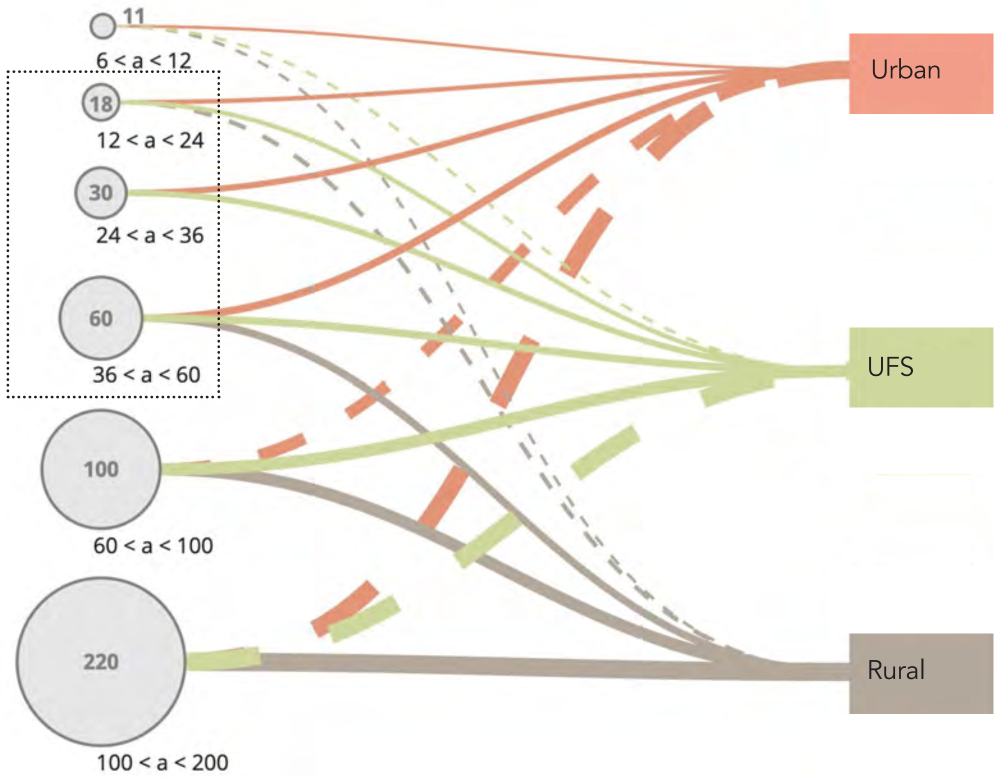
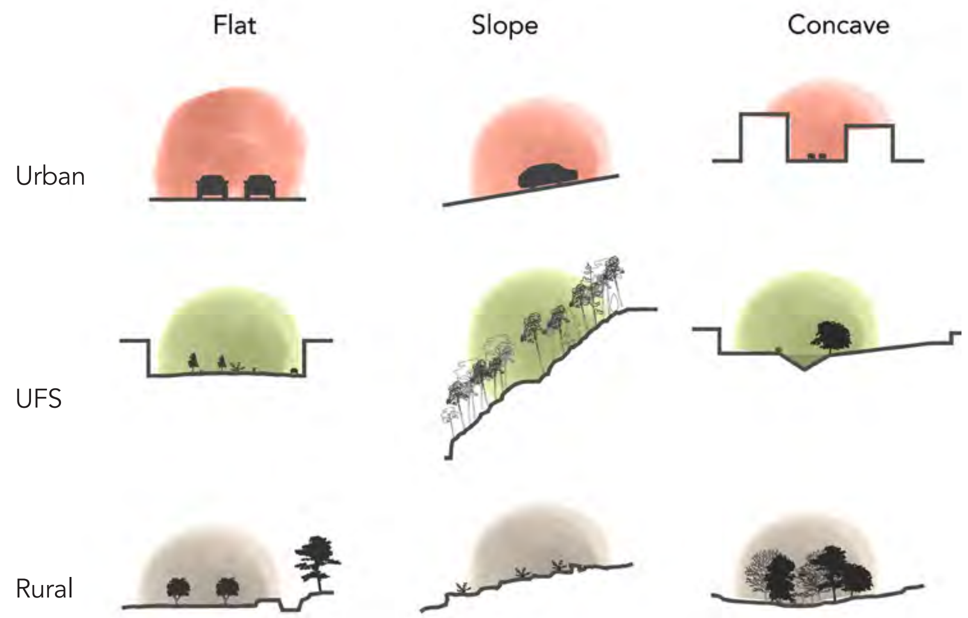


Figure 7.4: Relationship diagram between available size and land use.

Sizes ranging from 11m to 30m can be typical situations encountered in urban areas, while 60m may involve the conjunction of UFS next to a street with two vehicular lanes. This same situation may more rarely include available areas of 100m and 220m. However, this scale is much more standard in rural scenarios and for some larger UFS. The latter experiences significant variability in sizes. Accordingly, diameters of 18m, 30m, and 60m are applicable for the three situations.



- Unseal and make the ground more porous.
- Mulching
- Soil creation
- Decompaction

- Avoid erosion.
- Allow air convection.

- Ensure water captation and/or infiltration.

Figure 7.5: Matrix of land use and geomorphological conditions. Flat, slope, and concave situations represent the three geomorphological categories involved. Their relationship to wind and rainwater management requires distinct approaches, and consequently, their specific challenge solving.

7.2 DESIGNING A RESILIENT AND ADAPTIVE COOLING NETWORK

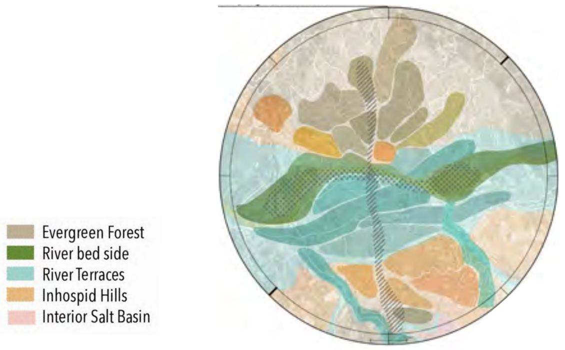


Figure 7.6: Proposal of habitat distribution with ecoregions according to geomorphological insights.

7.2.1 Strengthening Connectivity: Linking Cooling Patches Across Scales through habitat-based Strategies.

This network's connectivity is also approached structurally. The referent habitat planification helps to interconnect the minor interventions over time, making this proposal more flexible.

Figure 7.7: Interconnected network with green corridors through the city and with the surroundings.

The geomorphological characterisation described in Figure 6.39 helped delimit the different ecoregions shown in Figures 7.6 and 7.7. Each sub-ecoregion helps define the functions and strategies to enhance multiscalar connectivity and redundancy. As illustrated in Figure 7.7, the redundancy principle requires new, more significant parks at the city scale. An initial homogenous network is distributed throughout the city, prioritising green corridors aligned with predominant winds.

The close-up figure (Figure 7.8) illustrates a potential distribution of intervention for this area associated with the Carrasca Forest distribution. The proposal briefly expands on this habitat so that the development of the patch proposal following this section can be more specific.

Figure 7.9: Visualisation of a heat-resilient design of a continental Mixed Carrascal Forest with clustered species.

Mixed Carrasca Forest with Oak (Figure 7.9) is the region's predominant referent habitat enlarging. The strategy for this habitat is to support the initial growth of Holm Oak trees with Pinus halepensis and Pinus pinea, planting them close together to accelerate their growth, for afforestation strategies, and plant varied oak and underground vegetation in biodiversity improvement strategies.

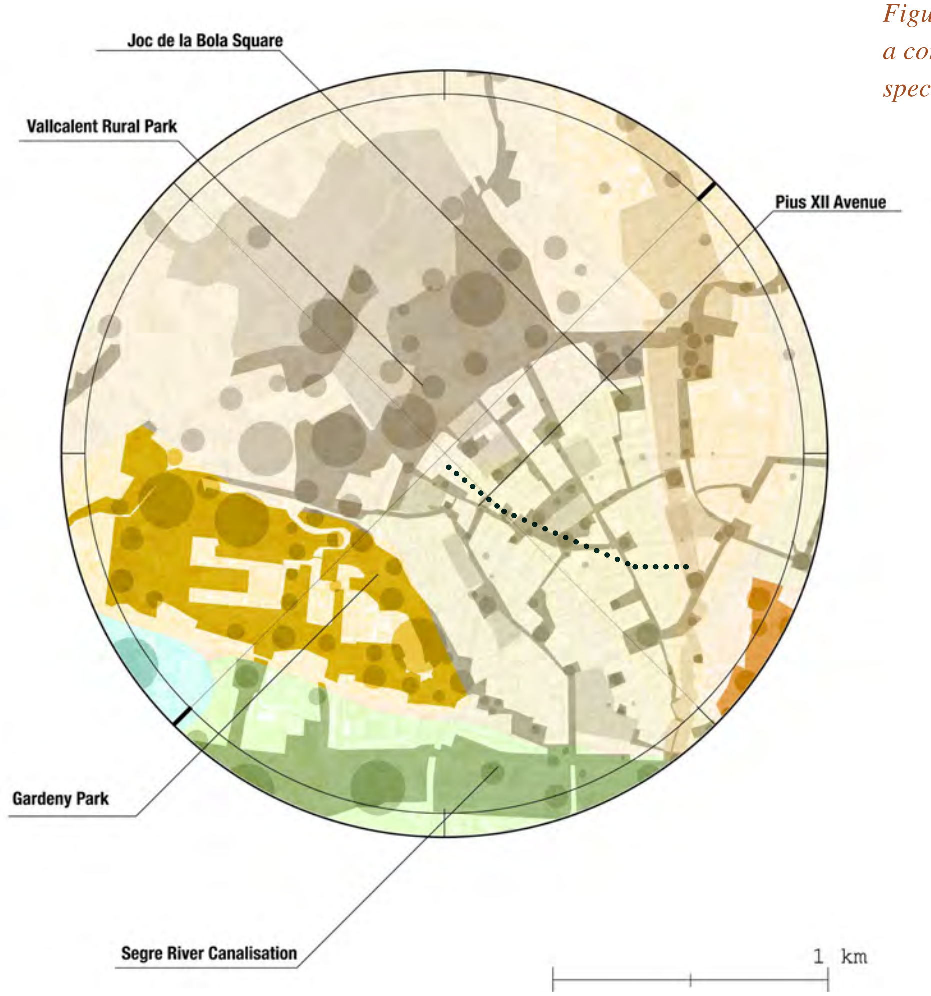


Figure 7.8: Zoom D with network proposal on the west part of the city, with some of the proposed intervention circles. Pius XII Avenue is one of the proposed green corridors for this ecoregion. It connects the rural area of Vallcalent with la Mariola and is aligned with the western winds.

7.3 TYPOLOGIES OF COOLING PATCHES: A SCALABLE INTERVENTION FRAMEWORK

Rural and existing urban free spaces [UFS] allow intervening in larger areas, but the differentiation between intervention zones and the types of interventions are two parallel studies. Similar to the restoration strategies, some might represent active intervention zones. In contrast, bigger ones can be a group of minor interventions with passive methods, such as green roofs in urban areas or restorative agricultural practices in rural areas (See Figure 7.11).

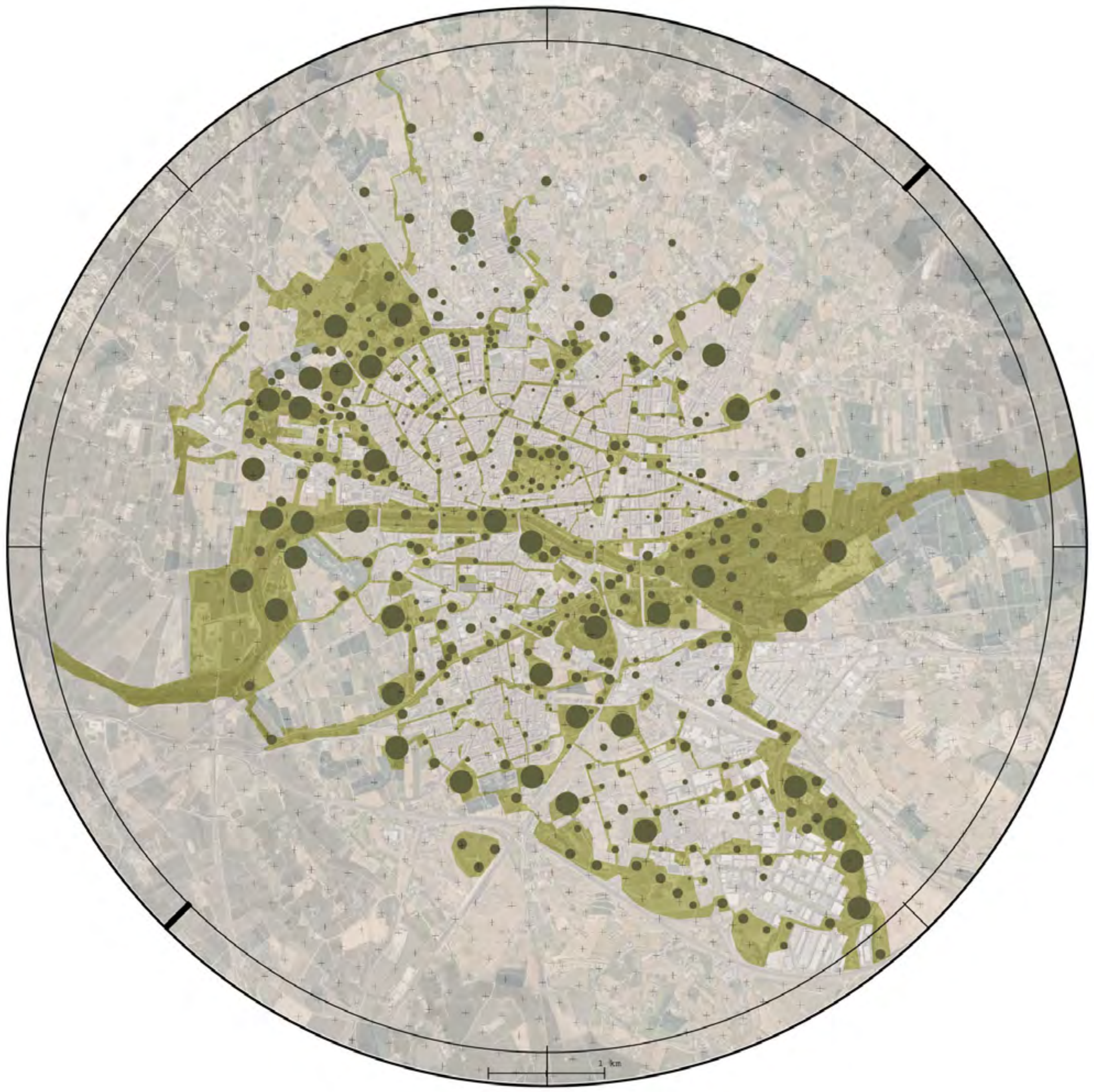


Figure 7.4: Distribution of patches with connectors.

7.3.1 *From Micro to Macro: Defining Cooling Island Categories*

Hotspots of ø8m

Figure 7.11: Small supportive hotspots. With a diameter of 8m, they include a focus function such as (a) reforestation on rural or UFS, (b) afforestation process without human accessibility. (c) Accessible nature in urban areas and UFS to improve biodiversity, and (d) recreation with a playground with vegetation to play and shade and some place for sitting.

Supportive island of ø11m

Figure 7.12: Minor intervention islands. It has a diameter of 11m and a surface of 95 m2. They include functions supportively: (a) Rainwater management, (b) small recreation hotspots including, and (c) Afforestation strategy. In urban areas, it can be in streets around 17m wide with reduced traffic or pedestrian broader than 12 m.

Small cooling island of ø18m

Figure 7.13: Small cooling islands. It has a diameter of 18m and a surface of 255 m2. Canopy covers 30% and over 60% of permeable ground, including retention and infiltration water systems. Urban situations require structural soils to avoid compaction and allow water draining;
(a) slow traffic is included, and (b) pedestrians are only allowed. Avoid medium heights to allow horizontal winds.

(c) Reforestation and biodiversity intervention over existing vegetation. Allow more significant species and include some cultural functions.

Medium cooling island of ø30m

Figure 7.14: Medium cooling islands. It has a diameter of 30m and a surface of 707 m2.
(a) Urban. Street junction or a UFS together with a broader street. Unique intervention with underground connections, allowing more prominent species to collaborate.
(b) Permeable GBI, Reforestation - Afforestation with biodiversity according to the ecosystem.

Medium-Large cooling island of ø60m

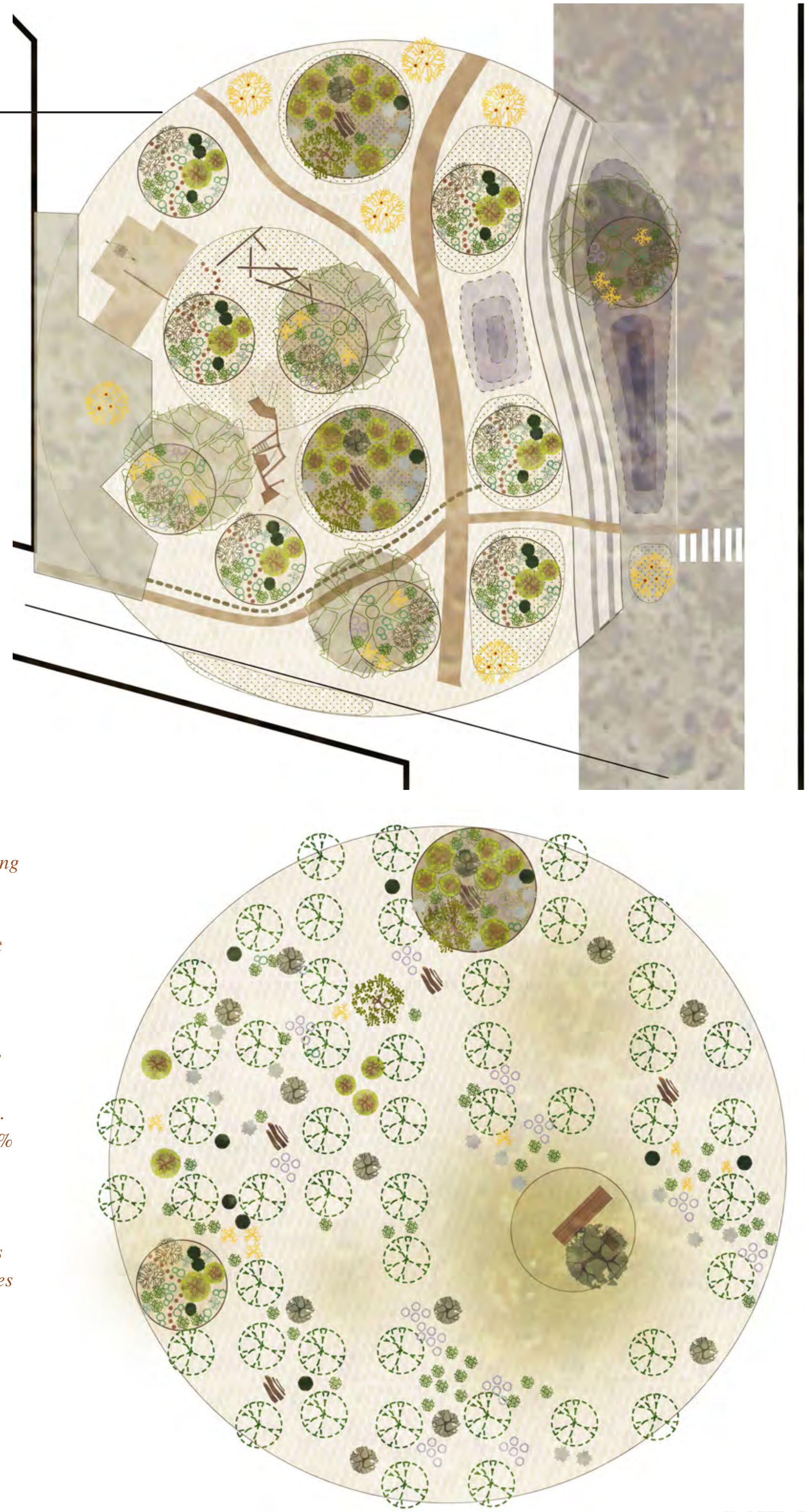


Figure 7.15: Medium-large cooling islands. It has a diameter of 60m and a surface of 0,03ha.
(a) In urban areas, UFS adjacent to wide streets can give this space situation. A strategy grouping varied typologies of minor interventions to make is as multifunctional as possible, with some areas sharing underground. Canopy covers 50% and over 60% of permeable ground, including retention and infiltration water systems.
(b) In permeable UFS, it requires supportive functions and increases biodiversity.

0 10 20 m

Scale 1:500

Large cooling islands ø100m

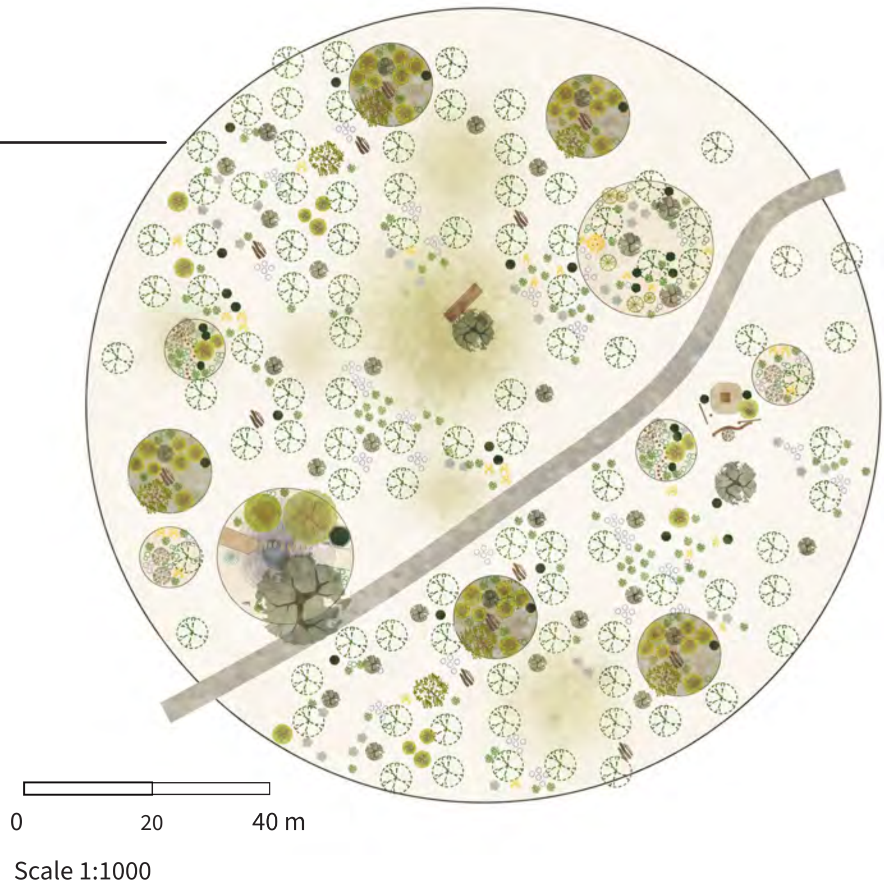


Figure 7.16: Large cooling islands. It has a diameter of 100m and a surface of 0,08ha. (a) UFS reforestation and biodiversity improvement. The surface becomes a delimited area where more minor interventions take place. (b) Urban situation for passive strategies (See Figure 7.18). (c) In rural situations, under the need of reforestation, afforestation with biodiversity according to the ecosystem. Smaller intervention areas allow temporary delimitation of access to areas using the Miyawaki method, for instance. Canopy covers between 30% and 60% of the land. Clustering vegetation.

XL cooling islands intervention ø220m

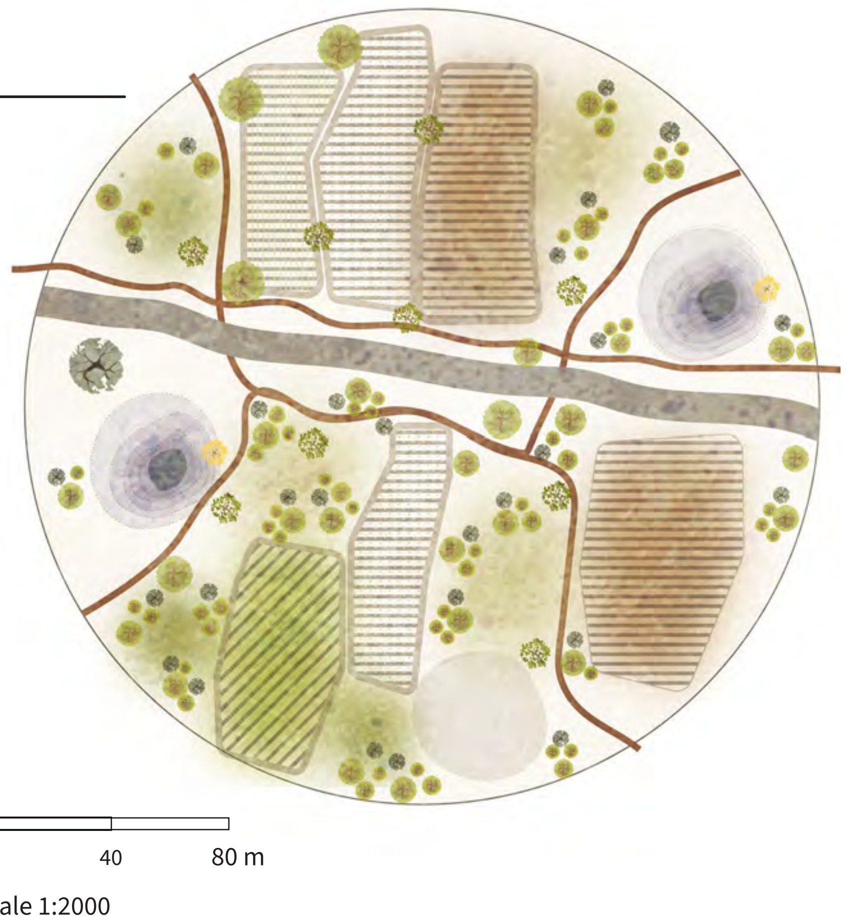


Figure 7.17: XL cooling islands intervention. It has a diameter of 220m and a surface of 0,35 ha. Primarily encountered in rural or liminal areas. Follows the same principles as Figure 7.16. including water features. Reforestation - Afforestation with biodiversity according to the ecosystem. Canopy covers between 30% and 60% of the land. Clustering vegetation.

7.3.2 *Case Study: Implementing Green Corridors Along La Mariola - Pius XII Avenue*

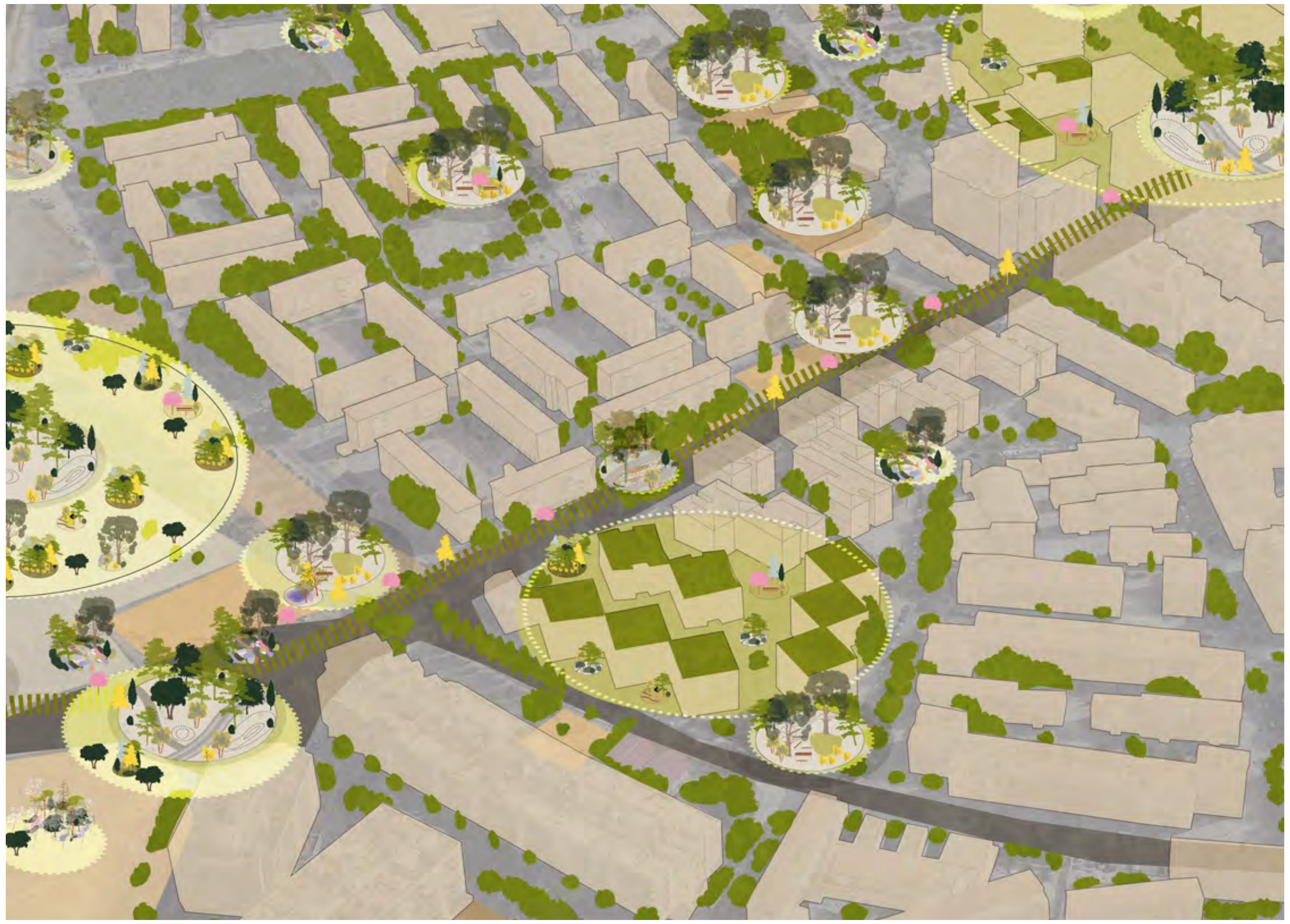


Figure 7.18: Axonometric view example of proposed interventions around the green corridor of La Mariola. It shows active interventions as previously described and passive intervention areas, where actions are taken to minimise the heat effects on vulnerable built environments or reduce wasted heat emissions.

7.4 REFLECTIONS AND FUTURE DIRECTIONS

Testing to define a friendly, heat-resilient rehabilitation guide has fostered knowledge about implementing heat-resilient rehabilitation from a design perspective while identifying the steps to ensure successful outcomes.

Notably, the absence of maintenance principles is striking. Likewise, the participatory approach requires collaboration to ensure effective implementation and long-term success.

CHAPTER

8

DISCUSSION

8.1 KEY FINDINGS AND INSIGHTS

This study investigated the impact of heat on a city in the Mediterranean region, which has significant rural areas. Subjacent connections in the literature between heat mitigation strategies, urban resilience, and restoration practices have not been explicitly combined. Still, this study has reiteratively and critically combined them to create new knowledge. Shortly, we found that health and connectivity are the subtle threads that connect them: a healthy habitat for healthy inhabitants.

8.1.1. Urban Form, Land Use, and Ecological Degradation in Heat Stress

LST analysis revealed temperature variations of up to 13°C across the study area, underscoring the thermal disparity between tree-dominated zones and barren or sealed surfaces. For instance, places such as la Mitjana Park and the other regions without specific use but with substantial tree canopy show a considerable temperature reduction compared with their immediate surroundings, such as the area between the Cappont neighbourhood and the Industrial area of la Vilanoveta.

Conversely, zones without trees exhibited high temperatures, regardless of land use. This finding highlights the critical role of vegetation in mitigating urban heat stress.

Even protected areas, such as the Nature 2000 reserve Mas-de-Melons, exhibited elevated temperatures similar to those of highly degraded zones like the abandoned Torres Salses development.

In line with findings by Keith & Meerow (2021), morphology emerged as a significant parameter influencing heat dynamics. While typological factors such as building form and materiality contribute to the urban heat island [UHI] effect, this study highlights the broader role of morphology—including surface roughness and structural configurations—in generating or mitigating heat stress. Surprisingly, the rural situations outside the Vallcalent area are concave and were identified as cooler temperatures under the LST study.

Materiality and roughness go hand in hand. The industrial area, with similar building forms, extensive roofs, and highly asphalted surroundings, was identified as a hotspot under the LST. The low roughness at the city scale, with building uniformity, illustrates what Gunawardena et al. (2017) pointed out as one of the parameters promoting UHI in dry and arid climates: stillness.

The urban-rural relationship risks the edges where urban needs expand and find their place. This observation, aligned with Aldoma's (2012) description of the high-pressure l'Horta gets from the city, was also made in the northwestern periphery of the Mariola neighbourhood, where formerly rural land has been

informally converted into parking areas. The resulting soil compaction and vegetation loss perpetuate land degradation and exacerbate heat stress.

Our findings on the impact of agricultural practices on heat stress were inconsistent due to the unpredictable use of water. Still, we consistently found that water and irrigation effectively reduce temperature, which coincides with findings claiming their use to mitigate heat. As a result of our research, it remains unclear whether the positive lectures we observed were due to the presence of water or the ecological state. This uncertainty underscores the need for further research and understanding in this area. In any case, the environmental aspect and water availability were crucial parameters to reduce the UHI effect.

8.1.2 Urban Planning and Design Strategies for Heat Resilience

Urban heat resilience requires an integrated approach incorporating GBI, ecological and intervention diversity, and spatial connectivity.

This research tested Ahern's (2010) heat-resilient principles to identify strategies in the local context of Lleida. The findings, in the analysis part, highlight that existing green infrastructure lacks the multifunctionality, biodiversity, and spatial connectivity required to mitigate heat stress effectively. The absence of diverse, interconnected green spaces results in fragmented systems with low resilience. Many of Lleida's green areas are isolated, species-poor, and specialised in function, making them unable to cooperate and provide scale-level heat mitigation.

The versioned ESTER 2.0 tool gave an ES value between the detailed GBI to compare their functions. We found that a wide variety of functions made the system less resilient. For instance, La Mitjana Park, despite its dense vegetation, is poorly positioned in terms of prevailing summer winds, limiting its ability to distribute cooling effects across the urban landscape. This underscores the need for urban planning strategies that prioritise horizontal cooling distribution by strategically placing green spaces.

Urban planning parameters such as permeability, tree canopy, and albedo (reflectivity) emerged as critical for enhancing heat resilience. Smaller-scale interventions, such as introducing tree clusters and sustainable small rainwater management in urban spaces, have demonstrated the capacity to significantly influence local microclimates. However, these efforts must be integrated into larger-scale strategic plans to ensure systemic connectivity and resilience.

The experimental study examined what a 300-metre grid would entail. Even in denser areas, it may require more minor interventions. However, a combination with supportive infrastructures, such as green roofs, could still enable connectivity on a larger scale.

Learning processes that allow adaptative planning and interventions are needed from dynamic measurement and observation. According to Ahern

(2011), this topic is critical for increasing resilience. It connects with Hintz's (2018) claims on the need to include measurement systems and adapt the thresholds to the local conditions, variabilities, and vulnerabilities.

8.1.3 Integrating Ecological Restoration with Heat Mitigation

The intersection between ecological rehabilitation and urban heat mitigation offers promising opportunities. This study explored the potential for integrating ecological rehabilitation strategies—particularly those involving tree-dominated systems—into urban landscape design to enhance heat resilience.

While ecologically significant, Mediterranean maquis and garrigue ecosystems offer limited tree coverage and may not provide optimal cooling benefits in dense urban environments. Moreover, xeric vegetation, native to extensive areas or clearance, conforms to a vital species compendium as part of the natural succession process toward a paraclimactic habitat. However, its role in heat mitigation in healthy ecosystems and other low-input landscapes remains underexplored, and cultural perceptions of xerophytic landscapes as "unproductive" challenge their acceptance.

Instead, mixed pine forests emerged as a more viable restoration model for degraded urban areas due to their established regional presence and capacity to thrive under dryer conditions while providing thermal benefits. However, their presence in the region also showed their competitive character, requiring other interventions to reintroduce a significant diversity of trees and underground covering. Mixed Carrasca Forest emerged as a habitat that could adapt to various conditions while increasing the overall diversity of stands. A paradox emerged: while traditional restoration principles prioritise ecosystem fidelity, rehabilitative strategies may require modifications to maximise heat mitigation benefits.

The study also emphasised the importance of collaborative, adaptive implementation processes. Smaller-scale interventions—such as pilot afforestation projects and ecological rehabilitation prototypes—offer opportunities to test species combinations, monitor local climatic responses, and engage citizens in planning. These prototypes can generate valuable knowledge to inform larger-scale strategies while fostering community acceptance and stewardship of restored landscapes.

8.2 INTERPRETATION OF RESULTS

The results of this study demonstrate that a holistic approach employing a multi-methodology is an effective research strategy for acquiring new knowledge. By examining the three concepts separately, we developed more comprehensive lectures. This enabled us to delve into each one's particularities and subsequently link them on a multi-scale.

The study's findings illustrate a systemic relationship between urban expansion, ecological degradation, and heat stress. Loss of natural ecosystems, supported by some agricultural practices, and soil degradation initiate processes of desertification that exacerbate UHI effects.

Lleida has the potential to establish a network of cooling islands through interconnected green spaces that enhance biodiversity and multi-scalar connectivity. However, successful implementation requires localised assessments to tailor solutions to specific urban contexts.

Furthermore, this study underscores the critical role of landscape planning and design in mitigating heat stress. By integrating heat resilience into planning frameworks, cities like Lleida can simultaneously promote systemic solutions that address environmental and human needs. This highlights the importance of adopting a holistic, collaborative approach to urban landscape planning that prioritises ecological restoration as a pathway to long-term resilience.

8.3 IMPLICATIONS FOR URBAN AND RURAL LANDSCAPES

This research has far-reaching implications for urban and rural landscapes. It highlights the urgency of addressing urban heat stress through integrated strategies that combine landscape planning, heat management, ecological restoration, and community engagement. Relying solely on behavioural adaptations or technological solutions is insufficient and inequitable, particularly given the socio-economic disparities exacerbating vulnerability to heat stress.

Moreover, this study underscores the need for regulatory frameworks that support ecological restoration and sustainable land management practices at both local and territorial scales. With special attention to the edges of the urban area, particularly the western part of the city, since its transition, degradation, or rehabilitation directly affects the city, Policies prioritising adequate habitat distribution, roughness with tree-dominated systems, protecting urban-rural ecological interfaces, and incentivising sustainable agricultural practices will be essential for building resilience to heat stress in Mediterranean cities.

8.4 STUDY LIMITATIONS AND AREAS FOR FURTHER RESEARCH

Despite its contributions, this study recognises several limitations that render the findings questionable while remaining open to further research on intertwining heat mitigation, resilience, and ecological restoration. Data availability was a significant constraint, particularly regarding urban weather patterns, tree distribution, and social vulnerability.

Reliance on satellite imagery for LST analysis faced temporal limitations since data did not match peak heatwave conditions. The heat map was created with limited information on Mars in 2023, months before severe droughts began. Although useful for the exploratory study, the LST measure became essential for observing surface responses. Satellite imagery had to align with heat waves for accurate calculation. From June 16-19, 2022, temperatures reached 41.9°C, exceeding 40°C for three days. However, the satellite passed over Lleida on June 24, post-heat wave, after rain on June 22 and strong winds on June 24. This situation invites further research using satellite data to integrate LST responses to rainfall.

On-site assessments of species' responses to heat stress were also not feasible, limiting the study's capacity to establish correlations between specific habitats and thermal behaviour. Additionally, the scarce presence of Carrasca and Maquia in the study area can challenge further studies on their cooling potential. Thus, additional research is needed to use these ecosystems as a reference for enhancing heat mitigation.

Other aspects that showed to be relevant but required a more context-specific study are urban form, building typologies, street aspect ratio and street orientation. Each neighbourhood has particularities that would necessitate an adapted approach to mitigate heat better.

Focusing on the ecosystems and prioritising the ecological perspective excludes other aspects that are also critical to consider in reality. For instance, the integration of complementing policies, analysis considering various actors' perspectives, and parallel education and communication strategies. For example, the proposal prioritised the landscape and human well-being over private vehicle transportation when looking for available spaces in the urban system. It implies reducing private traffic, which should be guided by other strategies such as public transport and other awareness interventions.

While some incursions on vegetation combinations occurred, they remained within the strategic landscape planning scale. Addressing vegetation combinations is superficially treated here, as it is a complex issue that requires further interdisciplinary research. A similar delimitation was set for this proposal's social and economic aspects.

8.5 STRATEGIC RECOMMENDATIONS FOR POLICY AND PRACTICE

This work reveals the seriousness of the issue, which contrasts with the actions taken at the local level. Therefore, the first group of recommendations reflects on the methodological improvements for accurate results.

Dynamic monitoring. Calculating multiple LSTs over various periods would help draw more complex and definitive conclusions about how agriculture practices and seasonal plant growth affect heat transmission. Comparative studies considering wind direction parameters could also provide precise information on the horizontal cooling distribution of cooling islands.

The Boverket tool ESTER 2.0 demonstrated considerable potential for analysing and guiding interventions. However, more accurate heat-mitigation variables, such as leave density, wind barriers, and wind direction influence, would need to be included. In this sense, multiple-profile collaboration, particularly with the expertise of ecologists and biologists, would enrich this study.

This collaboration would also help identify the right connections between new and existing habitats on a regional scale. The role of xeric ecosystems in mitigating heat remains unsolved, with few studies pointing to their capacity to maintain soil quality and avoid desertification. More research is needed to assess this role, create adequate plant palettes that integrate native and exotic plant species, and identify potential risks.

The second group of recommendations gathers the parallel studies that would help enrich this work. First, collecting weather data in an urban context is critical to understanding the impact of the UHI, creating weather indicators, and identifying climate variations in this setting, which aligns with Basarin's (2020) claim. Utilising urban sensors to measure air quality would also assist in creating a virtual image of the current state. Studying the life expectancy of urban trees can provide insights into future scenarios. A more accurate examination of the existing situation and monitoring the effects of tree canopy and thermal comfort levels would yield a clearer view of heat impacts to identify vulnerabilities and monitor future solution implementation.

Furthermore, sociological studies, focusing on social vulnerabilities and the superposition of socio-maps, would help delimit priorities and interventions. For them, the scale of the research and analysis must be the whole city, integrating the totality of the areas to justify equitable interventions and avoid green gentrification processes.

Referent ecosystems should be defined at this territorial level to rehabilitate and mitigate the heat of novel ecosystems. However, their integration in the planning structure is not protocolised, so governmental entities must standardise their integration and relationship with overview planning structures promoting supra-municipal collaborations. More flexible structures might better respond to delimiting areas needing action, such as climate adaptation.

Introducing natural plantings in new areas initially generates rejections in many communities. This practice has been used for over 30 years in northern European countries. Still, it counts with less experience in Spain or almost none in this region of Catalonia where the agricultural and production practices are more extended. Much experimental work, prototypes, and learning are needed in Lleida regarding plant combination and sustainable substrate adaptation to local conditions. Demonstration projects showcasing adapted versions of native ecosystems can help shift these perceptions by highlighting their ecological, aesthetic, and thermal benefits. Additionally, partnerships with local nurseries and knowledge-sharing with specialised providers will be critical to ensuring the availability of native, drought-tolerant species suited to local conditions.

In conclusion, much work is required on this serious matter. Even if particular interests are expressed, accurate, holistic, and collaborative studies are needed to ensure the applicability of solutions to reduce heat's impact on the population and landscape while improving resilience to future climate challenges. In this sense, an overview of integrative projects is necessary, and the structure of a green plan focusing on urban heat resilience would introduce ecological rehabilitation considerations that could effectively address issues benefiting humans, animals, and our habitat.

DISCUSSION

8.6 CONCLUDING REFLECTIONS: TOWARDS A RESILIENT URBAN FUTURE

This research underscores the urgent need to integrate heat mitigation strategies with ecological rehabilitation and resilience improvement in urban planning and design. As climate change intensifies the frequency and severity of heat waves, cities like Lleida must adopt adaptive strategies that address both rising temperatures and environmental degradation.

The study's findings demonstrate that urban form and ecological integrity significantly influence local heat dynamics. Green spaces, particularly tree-covered areas, are crucial in cooling the urban environment, while impervious surfaces and degraded lands contribute to extreme temperature variations. However, beyond the presence of vegetation, landscape structure, surface roughness, and water availability are key determinants of urban heat resilience.

Lleida's urban-rural interface presents a critical zone where land-use changes disrupt ecological functions and amplify heat stress. Unregulated urban expansion, soil compaction, and vegetation loss at the city's periphery highlight the need for a more strategic approach to urban growth—one that prioritises landscape connectivity and ecological function. Furthermore, industrial areas are underregarded as heat hotspots.

These insights reinforce the importance of landscape planning and design in addressing urban heat resilience. A multiscalar approach that incorporates green-blue infrastructure, nature-based solutions, and strategic land-use planning can help cities adapt to climate change while restoring ecological balance. Still, parallel research must be done on xeric vegetation's role in mitigating heat and the systematic studies of composition features of cooling islands.

In conclusion, building heat-resilient cities requires a paradigm shift towards integrated and adaptive planning. Collaboration among urban planners, landscape architects, ecologists, and policymakers is essential to designing cities that are not only livable but also ecologically sustainable. By embracing holistic, science-based approaches, urban environments can transform into resilient ecosystems capable of withstanding the challenges of a warming world.

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POPULAR SUMMARY

How Can Cities Beat the Heat? Lessons from a Mediterranean Case Study

As the planet heats up, cities are turning into sweltering hotspots. But could smarter design and nature's cooling powers help? A study in Lleida, Spain, shows how Mediterranean cities can combat extreme heat with strategic, eco-friendly planning.

Lleida tells a striking story of temperature extremes: during the same period, tree-filled areas by the water, like La Mitjana Park, are up to 13°C cooler than barren industrial zones. Why? Trees act as natural air conditioners, shading and cooling their surroundings. Meanwhile, materials like asphalt, concrete, and extensive metal roofs absorb heat, radiating it long after sunset. It's not just about adding more trees—it's about planting them in the right places and planning with purpose.

Agricultural practices also influence urban temperatures. Large annual crops near cities amplify heat, especially at night. In contrast, small patches of clustered pines and oaks create cooler, biodiverse "oases." These findings highlight the importance of creating small oases and reconnecting urban spaces with their closer surroundings.

So, how can cities like Lleida adapt and further mitigate heat stress? The study suggests building an interconnected "cooling islands" network through strategic urban planning. Small-scale interventions—vegetation clusters, unsealed and concave surfaces, shaded walkways, or green roofs—can have significant impacts when part of a city-wide cooling strategy. Connectivity is key: these green spaces must link to each other and nearby ecosystems, creating a cooling network that spans urban and rural boundaries.

Restoring native ecosystems, such as the evergreen forest, offers additional opportunities for heat mitigation. Reintroducing younger oak trees supported by pine trees planted closer together and other native vegetation covering the ground could regenerate degraded areas while providing vital cooling benefits.

Resilience lies in redundancy, diversity, and adaptability. With a mix of scalable solutions, from tiny gardens to sprawling parks, cities can create multiple layers of heat defence. Add ongoing community engagement and monitoring, resulting in an adaptable strategy for a changing climate.

A cooler, healthier city begins with thoughtful, nature-based design. By blending restoration, strategic planning, and collaboration, Mediterranean cities like Lleida can stay cool—and maybe even reverse the trend of urban overheating.

ACKNOWLEDGES

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To my friends, thank you for your respectful and unwavering presence. To Axel and my family, your support and encouragement have been indispensable. Finally, to those who are no longer here but have been very present here, and ever remain in my heart — Lea and Manel, this is for you two!

APPENDIX A:
METEORITICAL STATION IN LLEIDA

Table A.1: Information of EMA station. Source: Meteocat.

Codi EMA	Nom EMA	Municipi	Comarca	Data inici	Data Final	X UTM (m)	Y UTM (m)	Altitud (m)
VJ	Lleida - Pla de Lleida	Lleida	Segrià	16/09/1997	24/07/2013	303973	4607991	161
XW	Lleida - la Bordeta	Lleida	Segrià	24/07/2013	17/10/2018	304032	4607839	165
YJ	Lleida - la Femosa	Lleida	Segrià	21/08/2018		303421	4606345	170
VK	Raimat	Lleida	Segrià	31/08/1988		287655	4617757	286

Table A.2: Comparative between different stations and their proximity to the urban area.

Agency		meteo.cat	meteo.cat	AEMET	AEMET	AEMET
Ref. period		2007-2016	2007-2016	1983-2010	1983-2023	1959-1983
High over the sea (m)		97	286	185	185	199
Dist. Lleida center (Km)		21	14	3	3	0
Station name		Aitona	Raimat	Lleida 2	Lleida 2	Lleida 1
Med. Temperature ºC	Tma	14.8	14.1	15.0		
Max. Temperatue ºC	TXa	22.4	20.7	21.5	28.3	26.7
Hot days >30ºC	N	87.7	62.5	-		
Extreme Max. Temp ºC	TXxa	40.0	39.3	-		
Absolut Max. Temp. ºC	TMA				43.4	42.8
Date TMA					2019-06-29	1982-07-07
Anual rainfall (l/m2)	R	360.9	341.8	342	-	-

APPENDIX B:
LST CALCULATION..

Landsat 8

- I could download STP from usgs.gov . Landsat 8 has information related to temperature: Landsat 8 Operational Land Imager (OLI): April 2013 to present. The data can be downloaded through Earth Explorer https://earthexplorer.usgs.gov/

Spectral characteristics view. Spectral bands show different things, such.

Table B.1. Spectral band information.

Band	Wavelength	Useful for mapping
Band 6 - Short-wave Infrared (SWIR) 1	1.57-1.65	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 10 - TIRS 1	10.60-11.19	100 meter resolution, thermal mapping and estimated soil moisture
Band 11 - TIRS 2	11.50-12.51	100 meter resolution, improved thermal mapping and estimated soil moisture

https://www.usgs.gov/faqs/what-are-best-landsat-spectral-bands-use-my-research

Download information:

LC08_L2SP_198031_20220619_20220630_02_T1

Landsat 8-9 OLI/TIRS C2 L2

Landsat Product Identifier L1

- Field Definition: The naming convention of Collection 2 Level-1 image is based on acquisition and processing parameters.

Table B.2. Coding convention information.

L	Landsat
X	Sensor (C = Combined OLI/TIRS, T = TIRS-only (if Landsat 8 or higher), T = TM (if Landsat 4-5), O = OLI-only, E = ETM, M = MSS)
SS	Satellite (09 = Landsat 9, 08 = Landsat 8, 07 = Landsat 7, … 01 = Landsat 1)
LLLL	Processing Correction Level (L1TP = precision and terrain, L1GT = systematic terrain, L1GS = systematic)
PPP	WRS Path
RRR	WRS Row
YYYYMMDD	Acquisition Date expressed in Year, Month, Day
yyyymmdd	Processing Date expressed in Year, Month, Day
CC	Collection Number (02)
TX	Collection Category (RT = Real Time, T1 = Tier 1, T2 = Tier 2)

Format:

LXSS_LLLL_PPPRRR_YYYYMMDD_yyyymmdd_CC_TX

Example: LE07_L1TP_040033_19990929_20190822_02_T1

https://www.usgs.gov/centers/eros/science/landsat-collection-2-data-dictionary#landsat_product_id

To estimate Land Surface using Landsat-8

Table B.3. Values for estimating land surface.

Name	Symbol	value
Top of the atmosphere [TOA] Radiance	Lr	
Radiance multiplicative Band	ML	0.00033420
Radiance Add Band	AL	0.10000
	K1	774.8853
	K2	1321.0789
The wavelength of emitted radiance for Band 10	W	10.8
	C2	14388
Qualified and calibrated standard product pixel values	Qcal	
correction value for band10	Oi	
brightness temp	BT	
Normal DiffenceVegetation Index	NDVI	
Land Surface Emissivity	E	

Lr= ML x Qcal +A-Oi

0.00033420*Band10+0.10000-0.29

Conversion to top of atmosphere (TOA) brightness temp. (BT)

Kelvin to Celsius BT= K2/ln(k1/Lr+1)-273.15

1321.0789/ln(774.8853/Radiance+1)-273.15

K1= K1 Constant Band (No)

K2= K2 Constant Band (No)

Normal DiffenceVegetation Index (NDVI)

Using Band 5 and Band 4

NDVI= (Band 5-Band4) / (Band 5-Band4)

Proportion of vegetation (PV)

PV= square ((NDVI-NDVI min)/(NDVI max – NDVImin)

E=0.004*PV+0.986

Land Surface Temperature (LST)

LST= BT / (1+ W*BT/c2)*ln (E))

BT / (1+ 10.8*BT/14388)*ln (E))

APPENDIX C: EXPLORATIONS SUMMARY.

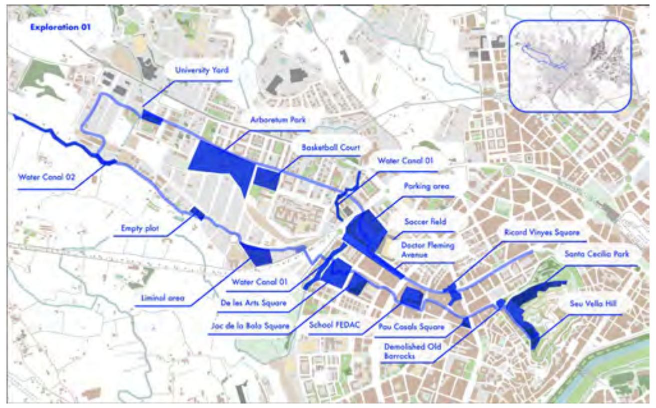


Figure C.1: Close-up map for exploration 1.

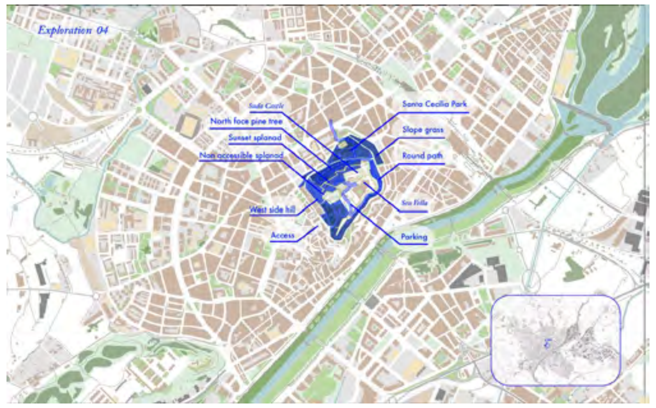


Figure C.3: Close-up map for exploration 4.

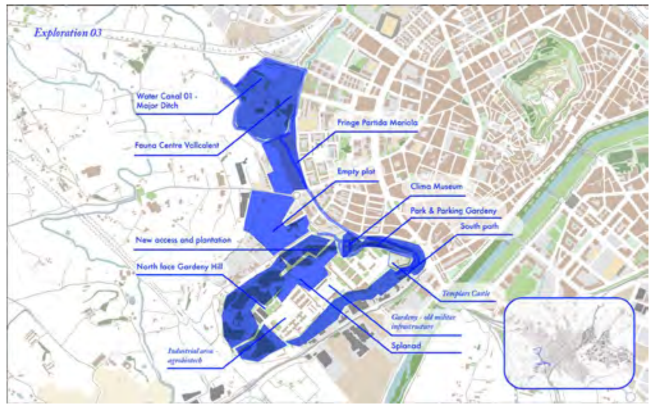


Figure C.2: Close-up map for exploration 3.

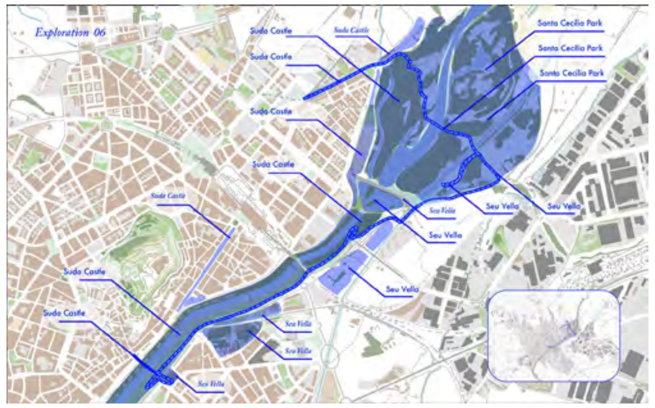
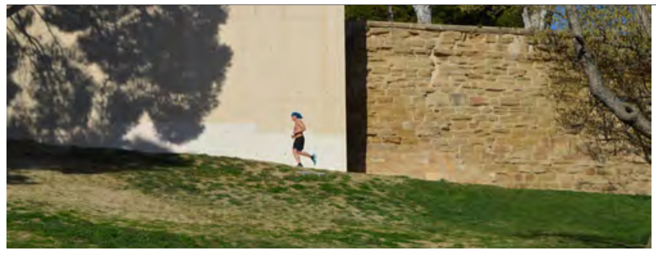


Figure C.4: Close-up map for exploration 6.


C.5


C.6


C.7


C.8


C.9


C.10


C.11


C.12


C.13


C.14

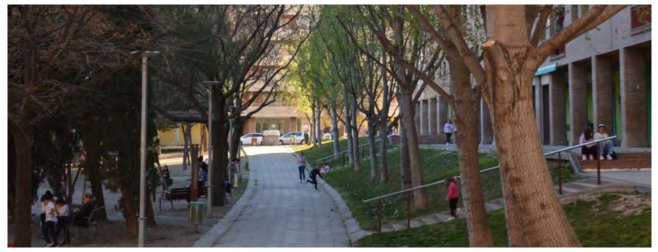

C.15


C.16


C.17


C.18


C.19


C.20


C.21


C.22


C.23


C.24


C.25


C.26


C.27


C.28


C.29


C.30

Figures C.5-C.44: Photos from the exploration 1.

Exploration 1


C.31


C.32


C.33


C.34


F.35


C.36


C.37


C.38


C39


C.40


C.41


F.42


C.43


C.44

Exploration 2


C.45


C.46

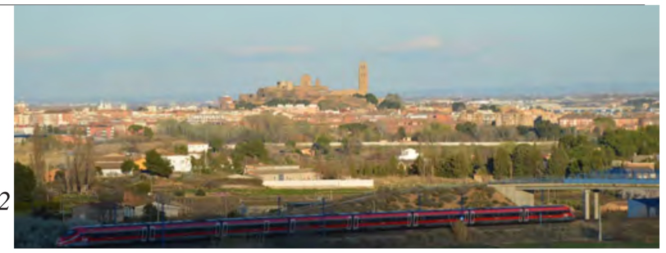

C.47


C.48


C.49


C.50


C.51


C.52


C.53


C.54


C.55


C.56


C.57


C.58

Figures C.45 -C.58: Photos from the exploration 2.

Exploration 3


C.59


C.60


C.61


C.62


C.63


C.64


C.65

C.66


C.67


C.68


C.69


C.70


C.71


C.72


Exploration 3.1


C.73


C.74


C.75


C.76


C.77


C.78


C.79

C.80


C.81


C.81


C.82


C.83


Figures C.59 C83: Photos from exploration 3; up the Gardeny Hill.

Exploration 3.2

C.84

C.85

C.86

C.87

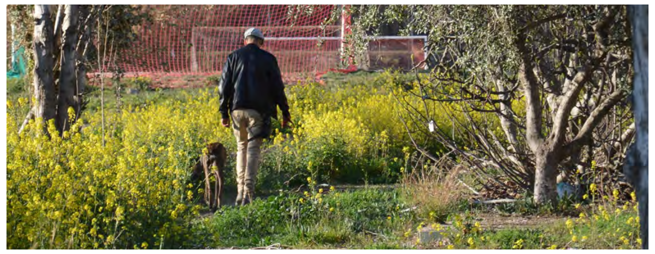
C88

C.89

C.90

C.91

C.92



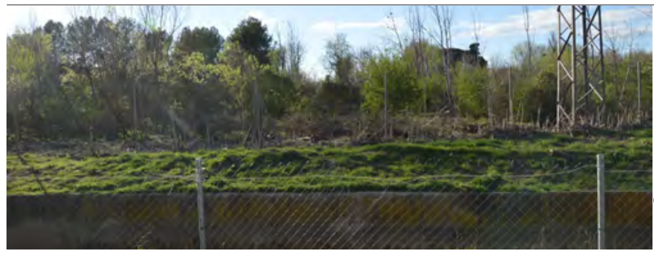
C.93

C.94

C.95

C.96

C97



C.98

C.99

C.100

C.101

C.102

C.103

C.104

C.105

C.106

Figures C.84 -C.106: Photos from exploration 3; zone Mariola and the rural Vallcalent.

APPENDIX D: CONVERSATIONS.

SEU VELLA'S HILL. MONDAY, 20 MARS 2023.

SAM.

Around 11:00, I met Sam in the area known as Santa Cecilia Park, the north side of the Seu Vella's hill. He is sitting on a squared stone that lies on the ground. On his back, a five-meter-tall stone wall, and on his top, pine trees cast the shadow, and around him, much rest of the methadone uses. He holds a beer but does not look drunk. We start talking at a certain distance. I explained that I was looking for wildflowers that appear at this time of the year, and he said that he likes this area a lot. He follows: "It is a higher point, with shade and cooler temperature from where one can see the buildings, a little bit far away. I like to be alone, and here is perfect if one takes care of where to put the foot". Think of the pine forest as a climate shelter.

SEU VELLA'S HILL. TUESDAY, 21 MARS 2023.

AUGUSTA.

Around 19:00, I went to one of the higher places where one can see the sunset, and I found Augusta, a woman in her early 30s that is there because she wanted to take pictures of a pendant that was a memorial with the landscape and the sunset. We started talking, and I asked her if she used to come there often. She said, "I used to go to the outdoor training facilities because I like to train outdoors, and here it is the only one. I live in Gardeny, there is a park there, but there is nothing to do there. Now, the under-construction building (she refers to the museum of the climate) is used, but there is absolutely nothing there, and they could also put a gym or playground."

And what do you think about the green area of Lleida? "I think there should be more outdoor gyms; every neighbourhood should have one. The one here is always very busy. And places to make picnics are necessary."

"There are no green areas! Well, that's not true; there are, but they are in bad shape. I went to the picnic area of Bell-lloc the weekend, and it was completely vandalised. I went to ask the municipality, and they told me that we could not make a fire until they fix it, but it is unclear when it will happen because there

is no money for that. All this is necessary to promote health; I think the municipality should invest more in green areas and their maintenance."

Replicability of outdoor infrastructure in other green areas. Playgrounds, gym, and picnic areas are also in Gardeny.

MARIOLA – VALLCALENT. FRIDAY, 24 MARS 2023.

ISMAEL.

Around 17:00. He walks with his Galgo dog on the brownfield that limits the urban area with the north orchard. After letting me know that he passes by this space twice a day, he continues showing his concern about the dirtiness of the area. It is used for throwing all kinds of objects and materials. He comments that from time to time when it is cleaned, it holds for a little while, but when some trash appears, the dirtiness proliferates. "The low maintenance inspires people to behave dirtier".

CANAL MARIOLA. FRIDAY, 24 MARS 2023.

PERE.

Around 18, I continued my exploration from the Mariola neighbourhood towards the northern orchard following the irrigation canal. I could not spot anyone, and suddenly, Pere appeared with his Colie dog. I asked him about using the canal as usual, and he explained that mornings and evenings, especially during the warmest months, become a popular walking dog route because it is circular and has a reasonable distance.

TORRE SALSES. MONDAY, 27 MARS 2023.

TATIANA.

Tatiana appeared around 11:00 when I was ready to pick up the car and leave the area. She was walking from the middle of the asphalted route towards the bridge that cross the train rails, connecting the new development with the Bordeta neighbourhood. After explaining that I am studying this area for an academic project, she opened up and explained that she likes walking there because there are no cars. Even if all streets of the development are built and asphalted with trottoirs and trees, they are closed to traffic with concrete elements. She comments that many others like to use this area to do power walking, alone or in company, or walking with the dog, and she adds that it would be very nice to have drinking water points and trash cans.

Other activities, such as evening car meetings, are also frequent. People who use this space to meet leave all the trash there.

APPENDIX E:

ECOSYSTEM SERVICES AND ESTER 2.0

Table E.2: ES Indicators based on ESTER 2.0 Indicators. Source: Boverket (2022a).

Biodiversity	Conditions for biological diversity	Does the project area contain natural or cultural environments that provide conditions for biological diversity?
	Nature or culture older than 30 years	Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
	Nature connected with other natural of cultural area	Is there connectivity in the area, i.e. does the project area contain natural or cultural environments that are connected to other natural or cultural environments outside the project area?
	Unusual nature	Does the project area contain an unusual nature type for the region?
	Protected trees	Are there trees particularly worthy of protection?
		Are there trees worthy of protection?
	Avenues	Are there avenues in the area?
	Protected biotop	Does the area contain any other generally biotope-protected structures (apart from avenues)?
	Key, signal, or red-listed species	Does the area contain any key species? Does the area contain any signal species? Does the area contain any red-listed species?
	Species, nature or environment covered by governamental action program	Does the area contain species, nature types or environments covered by national or regional action programmes?
	Water body	Is there an open body of water in or directly adjacent to the area?
	Marshes or wetlands	Are there marshes or wetlands in the area?
	Meadows	Are there meadows in the area?
	Pastures	Are there pastures in the area?
	Forest	Are there forest areas in the area?
	Mainly native species	Does the natural environment in the area consist solely or predominantly of native species?
	Free from invase species	Is the area free of species listed as invasive according to the Swedish Environmental Protection Agency or the EU's list of invasive alien species? Is the area free of species that could be considered invasive according to the project team, even though they are not on the list of invasive species?
	Linked biodiversity structures	Are there other structures linked to biodiversity that are important for the project to highlight in this area?
Ecological interaction		Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
		Are there trees particularly worthy of protection?
		Are there trees worthy of protection?
		Are there avenues in the area?
		Does the area contain any other generally biotope-protected structures (apart from avenues)?
		Does the area contain any key species? Does the area contain any signal species? Does the area contain any red-listed species?
		Does the area contain species, nature types or environments covered by national or regional action programmes?
	Structured green areas	Are there structured green areas?
	Noise free	Are there areas that are free from noise?
	Light pollution free	Are there areas free of light pollution?
		Does the project area contain natural or cultural environments that provide conditions for biological diversity?
Habitats for especies		Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
		Is there connectivity in the area, i.e. does the project area contain natural or cultural environments that are connected to other natural or cultural environments outside the project area?
		Does the project area contain an unusual nature type for the region?
		Are there trees particularly worthy of protection?
		Are there trees worthy of protection?
		Does the area contain any other generally biotope-protected structures (apart from avenues)?
		Does the area contain any key species? Does the area contain any signal species? Does the area contain any red-listed species?
		Does the area contain species, nature types or environments covered by national or regional action programmes?
		Is there an open body of water in or directly adjacent to the area?
		Are there areas free of light pollution?
	All faunal groups can move between natual environments	Is it possible for species within all faunal groups (birds, mammals, insects, reptiles, amphibians) to move between natural environments within the area? Are natural environments close enough to each other? Do the dispersal routes have the necessary characteristics to make movement possible for both flying and crawling animals?
	Sustainable habitat for existing species	Are there sustainable habitats for existing species and habitat types to remain in the long term (so-called favorable conservation status)?
Natural cycle	Water features that purify water	Are there ponds or wetlands that purify water via filtration, sedimentation or nutrient uptake, for example from nitrogen and phosphorus?
	Proportion of area covered by tree or bush crown (100/50/0)	How much of the area's surface is covered by the crown area of existing trees and shrubs?
	Can soil be formed through allowing organic matter	Is new formation of soil allowed on grass surfaces, in flowerbeds and under trees and bushes by allowing organic material to remain on the ground and rot?
	Undisturbed soil horizons	Are there undisturbed soil horizons in the area?
	Opportunities groundwater formation (ground and soil)	Do the ground and soil layers in the area allow opportunities for groundwater formation?
	Stormwater management and regulation	Are there natural or nature-based areas for stormwater management and regulation?
	Adequate supply of water and nutrients	Does the soil in green areas receive an adequate supply of water and nutrients?
Soil formation		Is new formation of soil allowed on grass surfaces, in flowerbeds and under trees and bushes by allowing organic material to remain on the ground and rot?
		Does the soil in green areas receive an adequate supply of water and nutrients?
		Are there undisturbed soil horizons in the area?
		How much hardened land is there in the area?
	Fertile soils	Are there fertile soils in the area?
Local climate	Area covered by the crown area of trees and shrubs	How much of the area's surface is covered by the crown area of existing trees and shrubs?
	Proportion of hardened land (20/50/100)	How much hardened land is there in the area?

	Larger green areas (>500x500)	Does the project area contain larger green areas or natural environments (>500 x 500 m) that contribute to air exchange such as city breezes?
	Bodies of water contribute	Does the project area contain bodies of water that can contribute to temperature equalization?
	Low vegetation covering the ground	Does the project area contain large areas of grass or other lower vegetation that can contribute to temperature equalization?
	Vertical vegetation on pergolas	Does the project area contain other vegetation on vertical structures (pergolas, trellises, walls) that contribute to shade and temperature equalization?
Erosion prevention	Stormwater management and regulation	Are there natural or nature-based areas for stormwater management and regulation?
	Erosion-prone soils protected with vegetation	Are there erosion-prone areas where vegetation, with above-ground and underground growth, protects the soil from rain and torrential rain?
		Are there areas where vegetation, with above-ground or underground growth, protects beaches from erosion from oceans, lakes or streams?
	Wind exposition protection with vegetaon	Are there areas where vegetation, with above-ground or underground growth, protects land exposed to wind erosion?
Protection extreme events		Are there natural or nature-based areas for stormwater management and regulation?
		How much hardened land is there in the area?
		How much of the area's surface is covered by the crown area of existing trees and shrubs?
		Does the project area contain larger green areas or natural environments (>500 x 500 m) that contribute to air exchange such as city breezes?
		Are there erosion-prone areas where vegetation, with above-ground and underground growth, protects the soil from rain and torrential rain?
		Are there areas where vegetation, with above-ground or underground growth, protects beaches from erosion from oceans, lakes or streams?
		Are there areas where vegetation, with above-ground or underground growth, protects land exposed to wind erosion?
	Great species diversity in tree population (no more than 5% of one species)	Is there great species diversity in the tree population?
		Are there hardwood curtains between buildings and forest stands?
	Flood plains	Are there floodplains in the area?
		Are the soils mainly permeable?
Air cleaning		How much of the area's surface is covered by the crown area of existing trees and shrubs?
		Does the project area contain larger green areas or natural environments (>500 x 500 m) that contribute to air exchange such as city breezes?
	Trees or shrubs that protect from air pollution	Are there trees or shrubs placed so that they can protect from air pollution from e.g. traffic or industry?
Sound regulation		How much hardened land is there in the area?
		How much of the area's surface is covered by the crown area of existing trees and shrubs?
		Are there vegetation curtains that can reduce the experience of road noise or the like?
	Natural structures that can mask noise	Are there natural structures that can mask road noise or similar?
Regulation and cleaning of water flow		Are there natural or nature-based areas for stormwater management and regulation?
		How much hardened land is there in the area?
		How much of the area's surface is covered by the crown area of existing trees and shrubs?

		Are there floodplains in the area?
	Mainly permeable soil	Are the soils mainly permeable?
Pollinisation	Meadows	Are there meadows in the area?
	Predominancy of natives species	Does the natural environment in the area consist solely or predominantly of native species?
	Suitable habitat for pollinators	Are there suitable places that can serve as habitats for pollinators?
		Is there a good abundance of flowering nectar- and pollen-bearing plants in the area?
		Is there a good supply of nectar- and pollen-bearing plants throughout the growing season?
Biological control		Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
		Is there connectivity in the area, i.e. does the project area contain natural or cultural environments that are connected to other natural or cultural environments outside the project area?
		Does the natural environment in the area consist solely or predominantly of native species?
		Is the area free of species listed as invasive according to the Swedish Environmental Protection Agency or the EU's list of invasive alien species? Is the area free of species that could be considered invasive according to the project team, even though they are not on the list of invasive species?
		Is it possible for species within all faunal groups (birds, mammals, insects, reptiles, amphibians) to move between natural environments within the area? Are natural environments close enough to each other? Do the dispersal routes have the necessary characteristics to make movement possible for both flying and crawling animals?
		Are there undisturbed soil horizons in the area?
		Is there a good supply of nectar- and pollen-bearing plants throughout the growing season?
	Valuable structures for pest control animals	Are there valuable structures for pest control animals in the area?
Food	Fertile soils	Are there fertile soils in the area?
	Gardens with cultivation or allotment	Are there gardens with cultivation, allotments or other urban cultivation in the area?
	Pasture for animals that provide food	Is there pasture for animals that provide food such as meat and milk in the area?
	Land for food production croops	Is there land used for growing crops for food production in the area?
	Hunting or fishing	Is the area important for hunting or fishing?
Fresh water	Food production in water features	Are there seas, lakes or waterways used for food production within or adjacent to the area?
	Public fruit, berries or mushrooms	Are there publicly available areas of berries, fruit or mushrooms?
	Water features that purify water	Are there ponds or wetlands that purify water via filtration, sedimentation or nutrient uptake, for example from nitrogen and phosphorus?
	Opportunities groundwater formation (ground and soil)	Do the ground and soil layers in the area allow opportunities for groundwater formation?
		Are there floodplains in the area?
	Water resources	Are there water resources such as lakes or streams in the area or nearby?
	Groundwater resouces	Are there groundwater resources in the area?
Raw materials		Is there pasture for animals that provide food such as meat and milk in the area?
	Forest for forestry	Are there forests used for forestry purposes?
		Is there pasture in the area for animals that provide raw materials for textiles and leather as well as manure?

	Land for fooder crops	Is there land in the area that is used for growing fodder crops?
Energi	Cultivation of fiber or health food	Is there cultivation of fiber crops or crops for the production of health food or biochemicals, both land and greenhouse or water-based crops, in the area?
	Other cultural commodities	Is there land that provides other types of cultural commodities or natural resources?
	Cultivation of energy crops	Is there cultivation of energy crops in the area?
	Forest for biofuel	Are there forests that are used for firewood or other biofuel?
	Residues from agriculture for biogas	Are residues from agriculture used for biogas?
	Other materials for energy production	Are there other materials in the area that are used for energy production?
Medicinal resources		
Recreation and physical health	Nature connected with other natural of cultural area	Is there connectivity in the area, i.e. does the project area contain natural or cultural environments that are connected to other natural or cultural environments outside the project area?
	Proportion of area covered by tree or bush crown (100/50/0)	How much of the area's surface is covered by the crown area of existing trees and shrubs?
	Public fruit, berries or mushrooms	Are there publicly available areas of berries, fruit or mushrooms?
	Used by residents of immediate area	Are green spaces in the area used by residents in the immediate area?
	Accessible to different conditions	Are green areas accessible to people with different conditions?
	Many people	Are there many people in the area?
	A green area in a distance of 300m	Is there a park/green area in or in close proximity to the area. Can you reach a park/green area within 300 m?
	Spontaneous physical activity	Are there green spaces for spontaneous physical activity?
	Paths or trails	Are there paths or trails for mobile outdoor life?
	Swimming possibilities	Are there natural places and beaches for swimming?
	Space for organised sport activities	Are there green spaces for organized sports activities?
	Natual playful environments	Are there natural play environments?
Mental well-being	Conditions for biological diversity	Does the project area contain natural or cultural environments that provide conditions for biological diversity?
	Nature or culture older than 30 years	Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
	Protected trees	Are there trees worthy of protection?
	Water body	Is there an open body of water in or directly adjacent to the area?
	Proportion of area covered by tree or bush crown (100/50/0)	How much of the area's surface is covered by the crown area of existing trees and shrubs?
	Vegetation curtains that reduce the experience of noise	Are there vegetation curtains that can reduce the experience of road noise or the like?
	Natural structures that can mask noise	Are there natural structures that can mask road noise or similar?
	Gardens with cultivation or allotment	Are there gardens with cultivation, allotments or other urban cultivation in the area?
		Are there publicly available areas of berries, fruit or mushrooms?
		Is there a park/green area in or in close proximity to the area. Can you reach a park/green area within 300 m?
		Are there paths or trails for mobile outdoor life?
	Varied surfaces create different climate condition	Are there surfaces that create conditions for a varied microclimate, for example shelter formation, sun exposure, shade?

	Quiet natural environments for relaxation and recovery	Are there quiet undisturbed natural environments for relaxation and recovery?
	Undisturbed natural environments	Are there undisturbed natural environments with the possibility of natural sound experiences, lapping waves, birdsong, etc.?
Aesthetic apreciation		Does the project area contain natural or cultural environments that provide conditions for biological diversity?
		Are there gardens with cultivation, allotments or other urban cultivation in the area?
		Are there publicly available areas of berries, fruit or mushrooms?
		Are there green spaces for spontaneous physical activity?
		Are there natural play environments?
	Suitable natural educational environment	Are there natural environments that are used for or would be suitable for nature education?
	Destination point for schools	Are there destination points for school excursions linked to the natural environment in the area?
	Information about the importance of nature	Is there information or guides about the importance of nature in the area?
	Walking distance of school	Are there natural environments in the area within walking distance of preschools/schools?
	Childrens stay and play	Do children stay/play in the area?
Social interaction		Are there gardens with cultivation, allotments or other urban cultivation in the area?
		Are green spaces in the area used by residents in the immediate area?
		Are green areas accessible to people with different conditions?
		Are there green spaces for spontaneous physical activity?
		Are there natural places and beaches for swimming?
		Are there natural play environments?
		Are there many people in the area?
		Is there a park/green area in or in close proximity to the area. Can you reach a park/green area within 300 m?
	Natual meeting areas for picnics, play and conversation	Are there natural meeting areas for picnics, play and conversation?
	Outdoor areas for events (related to nature)	Are there outdoor areas for events such as theatre, music, etc. related to nature?
Cultur heritage and identity		Does the project area, or parts of it, contain natural or cultural environments with long continuity (more than 30 years)?
		Are there natural environments or other natural structures or elements that create identity?
	Particular religious or historial places	Are there places or structures in the area that are of particular religious or religious-historical significance
	Particular cultural signifiance	Are there places or structures in the area that have a particular cultural (social and/or cultural-historical) significance?
Spiritual experience and sense of place		

APPENDIX F:
REFERENCE PROJECT SUMMARY.

Table F.1. Insights from Girona Shores Project, Spain. 2014-ongoing. Reference from the publication in Paisea (Franch & Lanzas 2020).

Strategy	Comments	Results
Pilot project	Started with a small intervention to create knowledge and collaborations.	Possibility of learning, revise and adapt.
Using existing municipal resources	Collaboration with municipal workers to create a tool to effectively manage multifunctional green spaces, while and "reeducate" them	Desig of Differentiated Management (DDM).
DDM	Incorporated non-spaces into the net of the city's multifunctionality green infrastructre without increasing maintainance budget.	50% with forest and scrubland management, 25% high grassland (mowing 1/year), 25% 4-8 mowing/year

Table F.2. Insights from the Urban Forest Strategy for Melbourne. (City of Melbourne 2014)

Strategies	Comments
Increase the tree coverage	A tree that is 20 years old provides 75% more ecosystem services than a recently planted tree.
Increase urban forest diversity	with "no more than 5% of one tree species, no more than 10% of one genus and no more than 20% of any one family" (City of Melbourne 2014:42) planted successively over the years and enhanced vegetation strata diversity.
Improve vegetation health.	Through proper tree selection, encourage healthy root growth by removing asphalt, annual checks, and ensuring water needs are met during summer.
Improve soil moisture and water quality	Integrate water-sensitive design whenever possible, introducing measures to capture and retain stormwater to increase water availability for tree roots. Also, improving the soil with structural soil allows oxygenation and water movement to benefit tree roots.
Improve urban ecology	Provide habitat to a wide range of wildlife species to increase biodiversity. It enhances ecological connectivity through corridors by letting dead trees where possible and developing programs to encourage interaction and raise awareness.
Engage with the community	

Insight from Millenium Forest Project. Malmö, Sweden. 2013-ongoing.

Based on the text publication in the magazine Landskab (Anderson et al. 2015), a visit during the autumn of 2022 with the guidance of Magnus Svensson and a later visit in the spring of 2023.

This project was visited in 2022 and has become a reference for exemplifying the transformation of farmland into a mature forest in twenty years, quite a short time. The project started in 2000 when citizens planted hundreds of trees on the city's edge, previously used as farmland, and stacked and further designed as a park in 2014, defining its structure and functions.

Condensing nature in the called 'meditations rums', a dynamic design of vegetation with varied qualities, and active maintenance are the keys of this project. The meditation rums are limited areas in the park that recreate biotopes with a suitable substrate and combination of plants and trees. Some have been closed to people's access for years so as not to create disturbances. One of the visited meditation rums has been closed for twenty years with a 1,5m high bush and recently opened by cutting an access entrance. Once accessible, it starts with the clearing-cutting process. Some trees with unique characteristics were planted with higher qualities, but the rest were small sizes of pioneers and secondaries. The planting form was also dynamic, grouping plantings at different distances to promote competition between plants. The clearing process and underlayer planting complementation are also crucial for the maintenance and project.

APPENDIX G:
NEWLY MUNICIPAL DOCUMENTS

Climate Emergency Declaration, 2022

The municipality showed awareness of the issue by signing the Climate Emergency Declaration 2022, which claims that the city has the "commitment to undertake coordinated and effective actions to provide solutions to the greatest challenge in human history" (Ajuntament de Lleida 2022:1). However, like many other European cities, actions are inconsistent, partial, and unplanned, not corresponding to the magnitude required.

The four unique proposals to do it are pretty vague: It aims to introduce environmental criteria in development politics, create an energy agency to boost renewable energies, introduce ecological criteria when contracting services, and finally, "improve mobility to make it more sustainable."

Plan for Climate Change, 2019

Following the demand of the European Commission to reduce the emissions of CO2, the Municipality of Lleida approved in 2009 the Action Plan of Sustainable Energy, which made the compromise to reduce the emission by 20% concerning the ones of 2005 (PCCL 2019). Following this initiative from the European Commission (EC), the municipality of Lleida developed a Plan for Climate Change (PCCL) in 2015. A new version was actualised in 2019, with the critical addition of a local compromise to reduce GHG emissions to 40% by 2030, following the European pact of Covenant of Mayors (paeria.es n.d.a).

The document compilates the potential risks for the city and proposes an action plan with mitigation and adaptation strategies. For instance, facing a reduction in water availability, a change in productive patterns, biodiversity affectation, an increase in the frequency of heat waves, pollution, and inhabitants' health issues are some of the questions considered. It also points to the high use of private vehicles. However, the suggested solutions only revolve around technological advancements, such as promoting electric vehicles, without proposing any improvements to public transportation. Most of the 39 measures to adapt the city to climate change align with this work's goal and findings. The primary actions considered include increasing biodiversity, implementing solutions to shield the city from extreme temperatures, enhancing water infiltration, and managing the green infrastructure. However, they are partially considered, focused on electrification, and do not consider any potential trade-offs.

Plan of the Green, 2022.

I received this working document from the Ecological Transition Department in January 2022; at that moment, it still required revision, and it was unclear if it would be published because it was some months before the municipal elections.

The Ecological Transition Department commanded the 'The Plan of the Green', a document with "the mission of analysing, defining and ordinating the green infrastructure of Lleida" (El Risell 2022). The document studied and classified the green structure on the urban and territorial scale and proposed several paths and nodes to connect existing areas of Nature 2000 and the other regions with high ecological value. However, the study and proposal focused on cultural ecosystem services. The proposal was based on identifying paths that pass by the maximum number of green spaces through streets that contain trees. Moreover, some areas by the paths are marked as possible new green areas. In general, the proposal does not contribute to improving any state of the green infrastructure in the urban environment or has a well-developed justification for the placement of the strategies and the overview strategy connectivity. Still, the study identifies the high-value spaces in the orchard, the natural interest habitats, and insightful detail strategies.

APPENDIX H: EXISTING HABITATS CHARACTERISATION

CARRASCA FOREST. MEDITERRANEAN EVERGREEN QUERCUS FOREST.

It is claimed to be the original ecosystem that might be naturally found in the region (Observatori del Paisatge 2010; Panareda 2011; Carrillo et al. 2018). It is classified as a Mediterranean habitat with Holm oak trees (Quercetum rotundifoliae), 'Carrasca' in Catalan, as the main character in combination with Quercus Ilex and other species represented in Table H.1, forming dispersed groves. The tree's morphology is also variable since it can develop from shrub trees to mature trees up to 12m tall, depending on the perturbations. However, it used to have a low tree canopy (EUNIS -Factsheet for Mediterranean evergreen [Quercus] forest n.d.). The 'Carrasca' in Catalan is a slow-growing species with high regenerative capacity.

It can include widespread transition with maquis in Mediterranean lowlands and foothills. In some regions, pinus halepensis, holm oak (Quercus Ilex), kermes oak (Quercus cocciferae), and maquis bushes share the habitat and represent a state in the regeneration process (Tomaselli 1977; Torres & et al. 1999).

CONTINENTAL MAQUIA AND GARRIGUE.

Maquis is the most typical form of vegetation in the Mediterranean region. It comprises a woody stand matorral, one of the most adapted to survive the Mediterranean environment because it can resist summer droughts (Tomaselli 1977). It is a complex formation with a multi-strata structure that offers a valuable habitat for different species and a high-resilience landscape in dynamic interequilibrium. It can include small trees, tall bushes, dwarf bushes, grasses, and microorganisms interacting in a dynamic equilibrium (Tomaselli 1977). Its rugosity avoids soil erosion when it rains, and the profound root systems of xerophilic plants create canals in the soils that can be used by other plants to capture water, improving the overall soil moisture. "According to De Bolos (1959), this practice of pulling up bushes is in all probability largely responsible for the desertification of many areas" (Tomaselli 1977:361). This kind of vegetation is critical to avoiding desertification.

Its high ecological values, floristic variety, and specialist species habitat have recently been demonstrated. Mas de Melons's protected natural area (7605,81 ha) contains a reduced example of maquis (0,384 ha) (EUNIS -Site factsheet for Secans de Mas de Melons-Alfés n.d.).

GARRIGUE AND STEPPE

Like Maquis, it is a matorral with the characteristic of being discontinuous and occurring on drier and poorer soils than Maquis (Rubel 1914; Tomaselli 1977). The EU Habitat directive also calls it "Thermo-Mediterranean and pre-desert scrub (EEA n.d.)." According to Tomaselli, this habitat can either consist of an average or low matorral.

Table H.1: Common list of species for Carrasca. (Observatori del Paisatge 2010; Panareda 2011; EUNIS -Factsheet for Mediterranean evergreen [Quercus] forest n.d.)

Type	Latin name	English name	Catalan name	Size (m)
tree	Quercus rotundifolia (ballota)	Holm oak	Carrasca	
	Quercus ilex L.	Holly oak	Alzina	5 to 25
	Rhamnus alaternus		Aladern	2 to 6
	Phillyera latifolia L.		Aladern de fulla ampla	2 to 6
bush	Quercus coccifera		Coscoll	
	Rhamnus lycioides		Arçot	1 to 3
	Rhamnus alaternus		Aladern	0,4 to 2
	Phillyera latifolia L.		Aladern de fulla ampla	1 to 2
	Buxus sempervirens		Boix	
	Pistacia terebinthus		Noguerola	
	Juniperus oxycedrus		Càdec	1 to 10
	Prunus spinosa		Aranyoner	
	Lionicera etrusca		Lligabosc	
	Genista scorpius		Ginesta	
	Thymus vulgaris		Timó	
	Agave ovatifolia			
	Mahonia fremontii	Fremont Barvery		
perenner	Brachypodium retusum		Llistó	
	Asparagus acutifolius		esparreguera boscana	
	Rubia peregrina		Rogeta	
	Teucrium chamaedrys		Camedris	0,2 to 0,3
	Carex humilis		Carex halleriana	
undergrowth	arbutus undo			
	Phillyrea angustifolia			
	Pistacia terbinthus			
	Rubia peregrina			
	Jasminus fruticans			2

PINE TREE FOREST FROM AFFORESTATION PROCESS.

It became a paraclimax formation or false climax where human intervention supported the pine tree forest and interfered in the succession towards the mixed forest climax (Tomaselli 1977). It corresponds to the G3.741 Iberian Pinus halepensis forest from the EUNIS classification (Generalitat de Catalunya 2017a).

Aleppo pine groups (Pinus Halepensis) were used for extensive reforestation processes in different parts of the Mediterranean basin during the XX century. They have adapted to degraded habitats since they grow fast and colonise disturbed areas quickly. The argument that they replaced the natural oak maquis forest, shrublands, and the garrigue in the region has been agreed upon (Tomaselli 1977; Maestre & Cortina 2004; Observatori del Paisatge 2010). The Table H.2 lists the common found species for this habitat with a transition towards the Carrasca forest.

Their impact on the overall ecosystem is debatable. When Pinus halepensis is a unique species, soil drought with a decrease of soil moisture, reduction of rainwater reaching the ground and increase of diseases worsen the ecological conditions of the area, preventing other species from colonising under their canopy (Maestre & Cortina 2004). An investigation line of species that can be seeded under pine forests to increase biodiversity and improve soil moisture exists, but more investigation should be done locally.

Due to their versatility and tolerance to heat and drought, Aleppo pine groups can be found in different green areas of the city. However, the biodiversity they provide is shown to be limited since Aleppo pine used to stand alone. The slopes of both urban hills contain fairly extensive colonies of Aleppo pine trees, as can be seen in Figures C.61, C.66, and C.81; one of the slopes of Gardeny Hill has a great shadow but is degraded underground.

Table H.2: Vegetation Composition for Pine Tree Forests with underground in a transition towards Carrasca. (Generalitat de Catalunya 2017a)

Type	Latin name	English name	Catalan name
tree	Pinus halepensis		Pi blanc
	Pinus nigra subsp. salzmannii		Pi negre
	Pinus sylvestris		Pi roig
	Quercus rotundifolia		
			palmito
bush	Lonicera etrusca		lligabosc
	Quercus coccifera		Coscoll
	Juniperus communis		Ginebre
	Rhamnus alaternus		Aladern
	Prunus spinosa		Aronyer
	Bupleurum frutiscescens		Botja groga
	Rosmarinus officinalis		Romani
	Erica multiflora		Bruc d'hivern
	Genista biflora		Ginestera
	Cistus clusii		Esteprola
	Genista scorpius		Argelaga
grasses			
	Asparagus acutifolius		Esparraguera boscana
	Rubia peregrina		Rogeta
	Teucrium chamaedrys		Camedris
	Brachypodium retusum		Llisto

RIVERLAND FOREST.

The fluvial ecosystem is one of the landscape units described by the Landscape Observatory extending along the Segre River. It includes the river, its affluents, and the crops surrounding the system (Observatori del Paisatge 2010). The phreatic level surrounding the river is relatively high, and the sedimentation process, wetlands, and lush vegetation create a habitat with high ecological values and shelter for many birds, amphibians, reptiles, and small mammals (Baraut 2009).

A typical vegetation composition of this habitat is represented in Table H.3.

RIVER TERRACES

Associated with more fertile soils, they primarily integrate agricultural landscapes in the region. Here, we can find a combination of fruit trees with poplar and ashes.

Table H.3: Commonly found vegetation composition in the Riverland forest habitat. (Observatori del Paisatge 2010; Generalitat de Catalunya 2017a)

Type	Latin name	English name	Catalan name	High (m)
main trees species				
	Populus alba	silver poplar	alber	15-30m
	Salix alba	white willow	salze blanc	10-25m
	Populus nigra	black poplar	pollancre	20-30
	P. canadensis	canadian poplar		20-40
	Ulmus minor	field elm	om	10-40m
secondari				
	Fraxinus angustifolia	narrow-leaved ash	freixes de fulla petita	20-30
	Alnus glutinosa	common alder	verns	20-30
shrubs				
	Rubus sp pl	blackberry		
	Rubus caesius		romegueró	up to 2m
	Rubus ulmifolius		esbarzer	
	S. purpurea	purple willow	mimbre purpurea	1-3m
	Crataegus monogyna		arç blanc	
climbers				
	Humulus lupulus	common hop	lupul	
	Hedera helix	ivy	heura	
	Cynanchum acutum			
Perennial				
	Potamion pectinae			
	Phragmition australis	common reed	canyissars	2-4m (6m)
	Molinio-Holoschoenion		jonqueres	

APPENDIX I: DESCRIPTION OF DETAILED STUDIED AREAS

Segre River Canalisation

This urban park is characterised by its lawn and broad pedestrian path with small sportive stops. It depends on lawn irrigation and does not look good even with continuous maintenance on a slope.

The canalisation consists of a man-made sank infrastructure between three and six metres deep, which becomes a barrier for cooling distribution between the core—the water feature—and the annexe urban area.

Some of the woody species stand aligned on the water or lawn edge. By the regular water line stand some dispersed trees, Acer negundo, and aligned by the main path are mostly poplar (Populus nigra).

La Mitjana Park

Dense alluvial forest with poplar, elder tree, ash, willows, a variety of shrubs, tamarisk trees, Rubus, waterlilies, reeds, yellow irises, and wetland grass plants. The high density of different layers gives a feeling of messy ecosystems outside the paths.

Santa Cecilia Park - North of Seu Vella Hill -

It is centrally located in the city. However, it is not a popular park because the slopes are inaccessible, and access is restricted due to landslides, cul-de-sacs, and shady activities taking over. However, an outdoor gym, the primary access to the old heritage part of the hill, and a sightseeing point keep this area alive.

The predominant shade of Aleppo pine trees (Pinus halepensis) without undergrowth is consistent and in a bad state, allowing superficial erosion. However, they protect against more severe erosion and landslides that the upper parts lacking vegetation experience.

Gardeny North

This area has similar characteristics to Santa Cecilia with the pines without underground. However, it is more prominent, and its tangential position in the city makes it an even more unexplored and unknown area, which offers a vast potential for accessible recreation.

Joc de la Bola Square

Big public courtyard connected to a school. Characterised by the large pine trees (Pinus pinea) that offer shade to the playground.

Humbert Torres Square

Predominated by Mediterranean hackberry trees (Celtis australis), this pedestrian street's intersection is mainly used as a square since it has a playground, benches and good shade. An area also has high Oleanders (Nerium Oleander) acting as a barrier, which gives extra shade but also divides the space visually, creating insecure feeling spaces which combine with a piece of lawn.

Street Navarra

This group of five streets, with a low aspect ratio, is dominated by the shade of Mulberry trees (Morus alba). The trees' canopy is the same height as the two floors of buildings, and the distance between trees is about five metres. Some discontinuities in the canopy might let air flow through, improving the night cooling capacity.

Rural Vallcalent

Situated by the ditch, a group of fruit tree crops form a relatively concave shape with a lower point in the landscape, offering good cooling conditions in rural areas. In the centre, the main house is surrounded by well-developed pine trees. The Major Ditch and the Centre of Fauna Vallcalent make it an interesting area for protecting the ES.

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