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Reframing Rural–Urban Transition Zones as Climate Buffers

*Morphological and Ecological Perspectives
for Climate Resilience in Lecce, Italy*

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Abstract

Climate change is altering the thermal conditions of Mediterranean cities and territories, and these changes do not affect all parts of the urban territory in the same way. Between the consolidated city and the open countryside lies a broad and heterogeneous space composed of agricultural land, dispersed settlements, infrastructures, residual open spaces, and fragments of ecological systems. Although these territories play an important role in the regulation of local microclimates, planning practice has often treated them as reserves for future urbanization or as spaces lacking a clearly defined role. This research focuses on the peri-urban fringe of Lecce, in the Salento peninsula of Puglia, and investigates the relationship between its ecological and morphological condition and the distribution of thermal vulnerability across the wider urban region.

The case of Lecce reveals an unexpected territorial configuration. The historic center, built largely in Pietra Leccese, records lower surface temperatures than both the twentieth-century and contemporary city surrounding it and the agricultural landscape beyond; the most critical thermal conditions are concentrated within the rural–urban interface. Here, the effects of the *Xylella fastidiosa* epidemic and agricultural abandonment have profoundly transformed the olive landscape: the reduction of tree cover has weakened evapotranspirative processes and increased the exposure of karst surfaces to solar radiation. At the same time, dispersed urbanization, infrastructural development, changing agricultural practices, and competing claims on land have reshaped the structure of the fringe. What emerges is a territory of friction — characterized by multiple forms of vulnerability and by the coexistence of processes that operate at different scales and according to different temporalities, in which thermal stress is the surface expression of deeper territorial transformation.

Understanding these conditions requires analytical tools capable of describing the heterogeneity of the rural–urban edge. To this end, the research develops the RUTZ Index (Rural–Urban Transition Zone Index), a composite instrument integrating morphological, ecological, and thermal indicators across an 8,625-cell analytical grid covering Lecce and its peri-urban territory beyond the Tangenziale ring road. Through geospatial analysis, multi-temporal remote sensing, and deep-learning feature extraction, the Index identifies the spatial variations through which the transition zone contributes to the regulation of thermal conditions. A complementary Heat Risk Index, calculated across 1,784 ISTAT census sections distributed throughout Lecce and its surrounding municipalities, relates these territorial conditions to patterns of demographic exposure and socio-spatial vulnerability.

The research interprets the rural–urban fringe as a territorial figure whose ecological and morphological characteristics influence the environmental performance of the urban region as a whole. From this perspective, the peri-urban edge appears as a strategic field for the urban and territorial project: the identification, protection, and regeneration of transition zones become part of a broader effort to reorganize the relationships between settlement, agriculture, ecological systems, and climate. The project is therefore concerned with the construction of new territorial equilibria capable of addressing ecological degradation, agricultural decline, and urban expansion within a common spatial frame.

KEYWORDS *Rural–Urban Transition Zones · Climate Buffers · RUTZ Index · Heat Risk Index · Urban Morphology · Microclimate Regulation · Reverse Urban Heat Island · Lecce · Nature-Based Solutions*

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List of Acronyms and Abbreviations

AHP	Analytic Hierarchy Process
ARVI	Atmospherically Resistant Vegetation Index
BSF	Building Surface Fraction
BSI	Bare Soil Index
Ca+b	Chlorophyll content (a + b)
CLMS	Copernicus Land Monitoring Service
Csa	Hot-summer Mediterranean climate (Köppen classification)
DIST	Dipartimento Interateneo di Scienze, Progetto e Politiche del Territorio
DL	Deep Learning
DS	Disease Severity (Xylella fastidiosa canopy classification)
ENN	Euclidean Nearest Neighbor (distance)
EPSG	European Petroleum Survey Group (coordinate reference identifier)
FCo	Fractional Cover
GIS	Geographic Information System
HRI	Heat Risk Index
ISF	Impervious Surface Fraction
ISTAT	Istituto Nazionale di Statistica (Italian National Institute of Statistics)
LAI	Leaf Area Index
LCZ	Local Climate Zone
LST	Land Surface Temperature
MESH	Effective Mesh Size
MSPA	Morphological Spatial Pattern Analysis
NDMI	Normalized Difference Moisture Index
NDVI	Normalized Difference Vegetation Index
NP	Number of Patches
OSAVI	Optimized Soil-Adjusted Vegetation Index
PD	Patch Density
PUG	Piano Urbanistico Generale (General Urban Plan)
RUTZ	Rural–Urban Transition Zone (Index)
SAVI	Soil-Adjusted Vegetation Index
SMI	Soil Moisture Index
SUHI	Surface Urban Heat Island
SVF	Sky View Factor
TCD	Tree Cover Density
TVDI	Temperature Vegetation Dryness Index
UHI	Urban Heat Island

UTFVI	Urban Thermal Field Variance Index
WMS	Web Map Service
WUDAPT	World Urban Database and Access Portal Tools

Glossary of Key Terms

Thermal Margin

The author's conceptual frame (developed in collaboration with Prof. Antonio Di Campli) for the peri-urban edge as a border space where climatic variation intertwines with social and economic marginality; the territorial condition the RUTZ Index is designed to measure.

RUTZ Index

Rural–Urban Transition Zone Index. The thesis's original composite spatial instrument, integrating morphological, ecological, and thermal indicators across a 100-meter fishnet grid to measure the buffering capacity of the peri-urban fringe.

La Pietra

The lithic core. The first of the three interpretive ecologies: the dense, high-albedo limestone urban fabric of historic Lecce.

Il Giardino

The vegetated transition. The second ecology: the orchard mosaic and surviving canopy that performs the active evapotranspirative cooling of the fringe.

La Frangia

The conflictual margin. The third ecology: the degrading peri-urban zone of abandoned agriculture, bare karst, and stalled urbanization where the climate buffer is failing.

Climate Buffer

A landscape whose morphological and ecological configuration measurably moderates the thermal regime of the territory adjacent to it; the thesis's reframing of the rural–urban transition zone.

Reverse Urban Heat Island

The locally observed inversion of the canonical urban heat island, in which the dense limestone core of Lecce runs cooler than its bare, canopy-depleted agricultural fringe.

Città diffusa

Diffuse city. The dispersed, low-density settlement pattern characteristic of the contemporary Italian peri-urban landscape.

Pietra Leccese

The fine-grained, pale calcarenite limestone of the Salento, whose high albedo and thermal mass give the historic core of Lecce its distinctive thermal behavior.

Masseria

A fortified agricultural compound of the Salento (16th–17th c.), functioning as a self-contained passive climate-management system.

Muretto a secco

Dry-stone field boundary wall; a mortarless double-skin structure (UNESCO Intangible Cultural Heritage, 2018) that performs thermal and microclimatic functions across the agricultural matrix.

Pajara

The Salento-native conical dry-stone agricultural field shelter; a mortarless corbelled structure functioning as a passive thermal regulator.

Trullo

The corbelled dry-stone residential structure of the Itria Valley (northern Puglia), included as a regional reference for the dry-stone corbelling tradition, distinct from the Salento-native pajara.

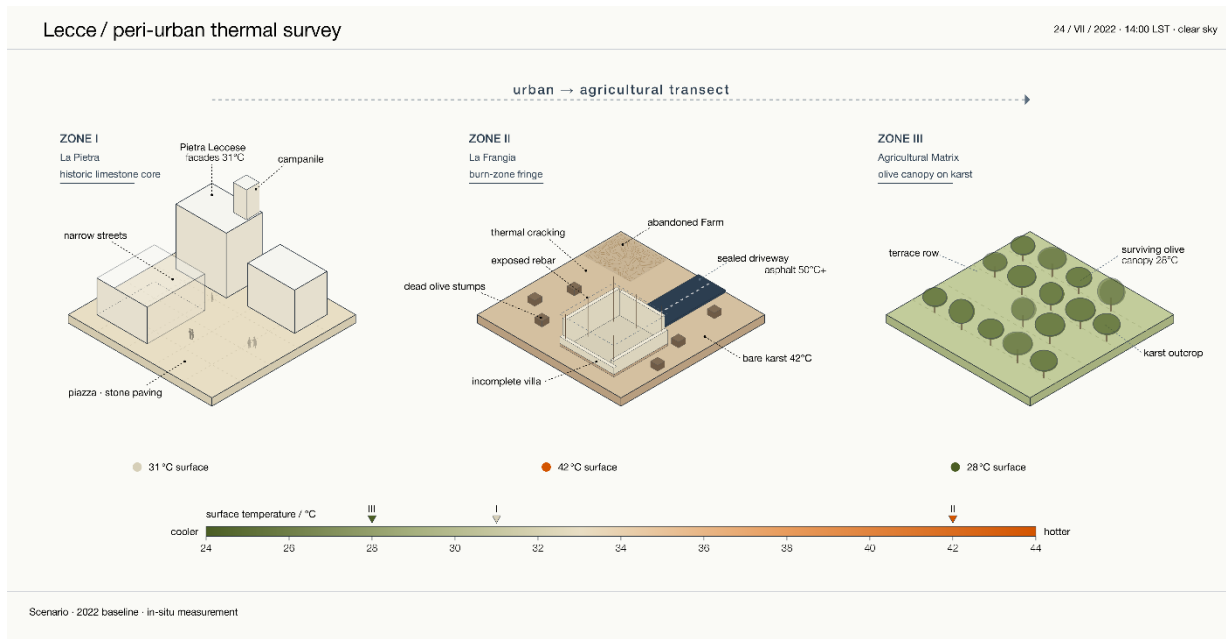
Chapter 1

CHAPTER 1 - Introduction: The Mediterranean Heat Hotspot

1.1 Background: Climate Stress and the Mediterranean as Climate-Change Accelerator

On the 24th of July 2022, the countryside around Lecce burned hotter than the city itself. The historic limestone core of the provincial capital, shaded by its own density, cooled by centuries of material intelligence embedded in the pale Pietra Leccese facades, registered surface temperatures well below those of the agricultural margin beyond its edge. It was the fringe that accumulated the highest heat in the province: the burn zone of bare karst soil, of dead olive stumps still vertical but stripped of canopy, of incomplete villa developments and sealed driveways that had accumulated exposure without accumulating either the shade of the countryside or the albedo of the city. De Razza and colleagues, mapping Land Surface Temperature from Landsat-8 imagery across the Salento territory during that heatwave, confirmed what the landscape already registered: at their peak, bare and sparsely vegetated peri-urban soils reached 42.25 °C, against 31.44 °C on the Pietra Leccese limestone of the historic urban fabric, and 40.32 °C on the impervious surfaces of the city center (De Razza et al., 2024). The territory most commonly treated as marginal to the city was, on that day, measurably the hottest terrain in the province. This thermal inversion is not an anomaly to be explained away. It is the diagnostic finding at the center of this thesis.

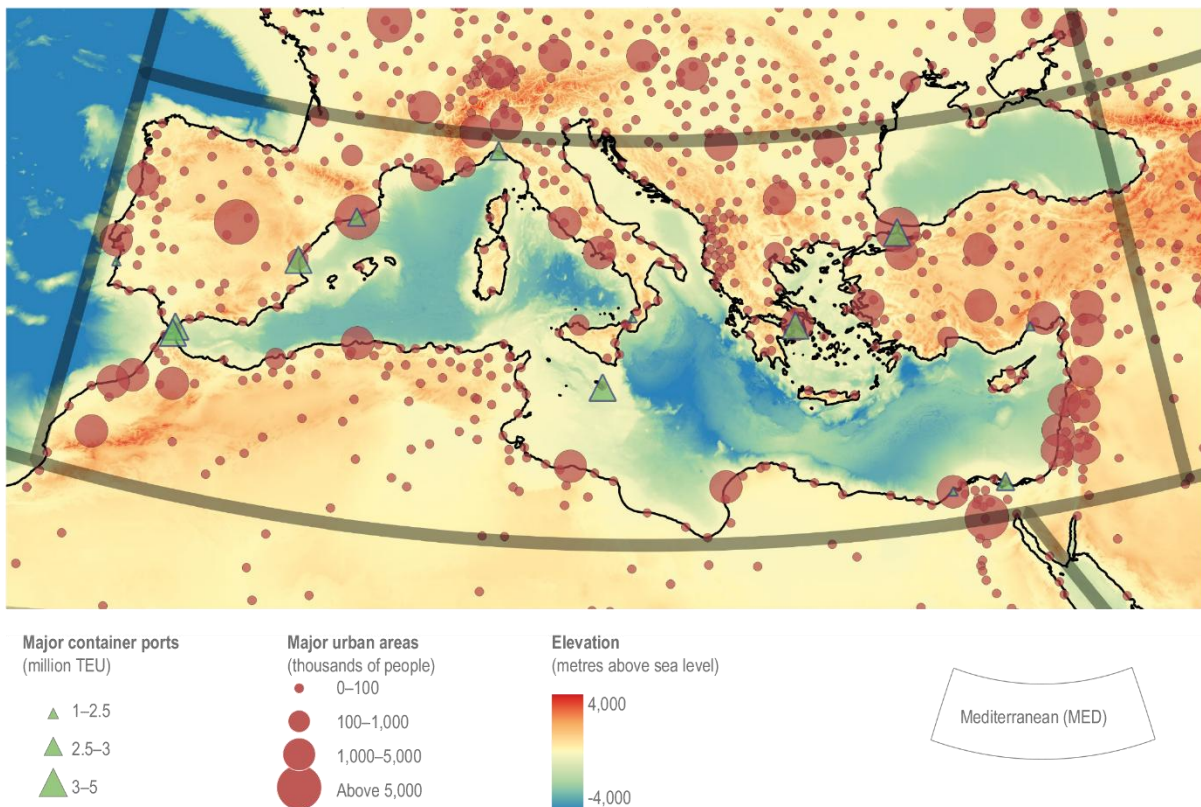
Figure 1.1 Thermal Gradient Across the Lecce Peri-Urban Fringe, 24 July 2022



Note. Schematic illustration of the three thermal zones reading left to right across the peri-urban gradient: La Pietra, the cool karst-agricultural matrix (~31 °C, intact olive canopy, Pietra Leccese albedo advantage); La Frangia, the exposed peri-urban burn zone (~42 °C, sealed driveways, dead olive stumps, bare soil); and the historic limestone core (intermediate temperature, density-generated mutual shading). Original illustration by the author.

The Mediterranean basin frames this condition at its largest scale. The Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report's Cross-Chapter Paper on the Mediterranean Region confirms what the Salento data already registers: the basin is a documented climate-change hotspot, warming at a rate consistently and significantly exceeding the global mean (IPCC, 2022). Lionello and Scarascia (2018), synthesizing 28 CMIP5 global climate model simulations across the combined historical and projected period 1901–2100, quantify what that excess means in precise climatic terms: annually, the Mediterranean warms approximately 20% faster than the global mean surface temperature; in summer, that amplification reaches 50% above the global rate, the basin accelerating at 1.5 times the planetary average during the season when heat stress is most lethal. Across continental land areas north of the basin during the summer months, the projected warming rate can reach locally up to twice the global average. This amplified signal becomes statistically significant during the 21st century, distinguishing a 20th-century period when regional and global temperatures tracked each other closely from a 21st-century trajectory of accelerating divergence. Lecce sits within this trajectory not as a point on a continental average but as a specific sub-regional vulnerability: the Csa climate regime, the hot, dry-summer Mediterranean type in the Köppen-Geiger classification produces long, arid summers with minimal nocturnal cooling and intense solar radiation absorbed and re-radiated through limestone karst surfaces that carry daytime heat well into the night. Southern Italy, and Puglia in particular, sits at the intersection of projected land degradation, prolonged drought, and urban heat amplification that the IPCC identifies as among the highest-risk sub-regional conditions in the entire Mediterranean system.

Figure 1.2 The Mediterranean Region: Topography, Urban Areas, and Container Ports



Note. From "Cross-Chapter Paper 4: Mediterranean Region," by E. Ali, W. Cramer, J. Carnicer, E. Georgopoulou, N. J. M. Hilmi, G. Le Cozannet, and P. Lionello, 2022, in H.-O. Pörtner et al. (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 2238, Figure CCP4.1). Cambridge University Press. <https://doi.org/10.1017/9781009325844.021>. CC BY 4.0.

Lecce's exposure within this basin-scale trajectory is not merely climatic. It is material and territorial, inscribed in three compounding pressures that converge most violently in the fringe gradient zones. The first is the *Xylella fastidiosa* bacteriological crisis. Beginning in 2013 and advancing southward through Salento's olive groves with ecological completeness, *Xylella* has removed the tree canopy that historically provided shade, evapotranspiration, and moisture regulation across Lecce's peri-urban fringe. The biological behavior that drives the ecological effect is no more. The consequence is thermal: the fringe has lost its principal means of regulating its own heat. What persists where olive groves once stood is white-cream bare karst soil mixed with sprawled herbaceous cover under direct solar radiation, a landscape whose thermal exposure is structural, inscribed in the morphological and ecological state of the territory, not recoverable without deliberate intervention. The second pressure is low-density peri-urban expansion. The sprawling villa developments and industrial shed peripheries that have advanced across Surbo, Lizzanello, and Cavallino have sealed productive agricultural soil without achieving the density that generates the thermal compensation mechanisms of genuine urban fabric: mutual shading between buildings, reduced sky view

factors, the cool-canyon effects of narrow street networks. They have the exposure of the countryside without its vegetative shade; they have the impervious fractions of the city without its albedo. Pappaccogli et al. (2024), documenting heatwave dynamics at the ARPA station in Lecce, recorded an urban heat island intensity of 2.60 °C during severe heat events, with the fringe contributing to thermal loading rather than moderating it. The third pressure is demographic. Aging in the satellite towns concentrates the population most vulnerable to heat-related mortality, residents aged 65 and over, in precisely the fringe zones where thermal degradation is advancing at an accelerating rate. These are not three separate planning problems. They are three aspects of a single territorial condition.

The territory where these pressures converge, the rural-urban transition zone, and the thermal margin of the city is the subject of this thesis. It is not a planning category in the administrative sense of a boundary drawn between zoning districts. It is what has been defined here as the Thermal Margin: a material and social border space where climatic variations such as heat, humidity, radiation, drainage, and ventilation — intertwine with conditions of economic, infrastructural, and social marginality, leading to the production of hybrid forms of environmental and design adaptation. In Salento, it is the threshold where widespread urbanization and declining agriculture generate extreme microclimate conditions and landscapes of conflict between production, abandonment, and new building colonization. That thermal margin is burning. And it is, as yet, unmapped at the resolution its complexity demands.

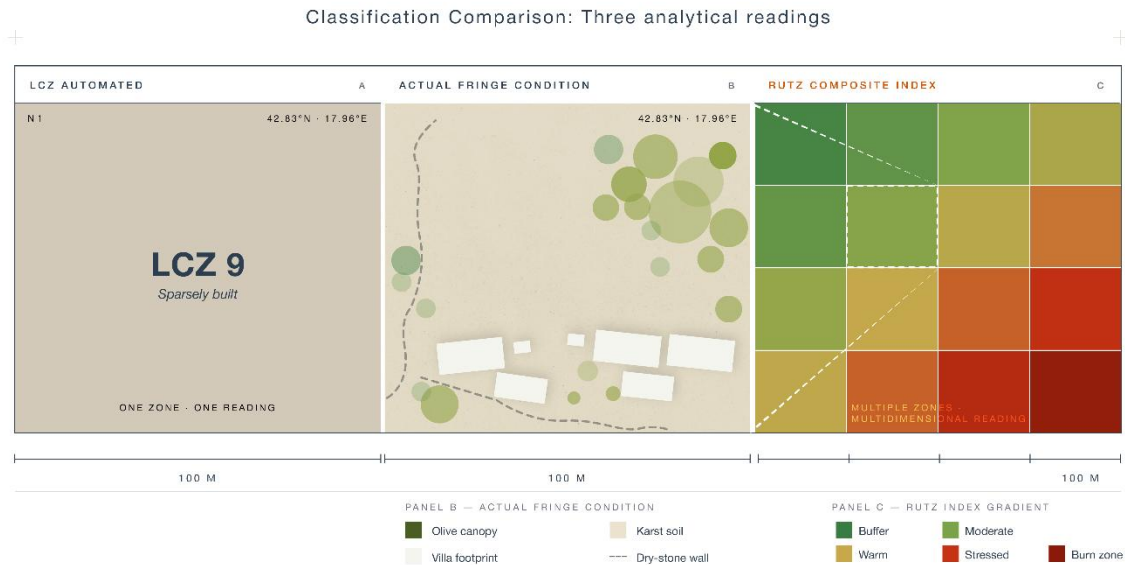
1.2 Problem Statement: The Neglected Fringe and the Urban Shadow Paradox

Every city produces a shadow, not the architectural shadow of towers falling across streets, but the analytical and political shadow a city casts over the territory immediately beyond its administrative edge. The peri-urban fringe lives in this shadow. Allen (2003), writing on the extended metropolitan region, identifies the peri-urban interface as a zone of intense and poorly governed socio-ecological transformation, a territory where urban and rural land uses collide under conditions that neither urban nor rural planning frameworks are equipped to regulate. Iaquineta and Drescher (2000) locate the methodological difficulty at its root: the peri-urban is not a land use but a process, characterized by dynamism, heterogeneity, and the simultaneous presence of incompatible spatial logics that resist the categorical tidiness on which both urban and rural planning depend. Together, these scholars establish that the peri-urban interface, the thermal margin, carries a rich intellectual genealogy and a persistent methodological problem: it cannot be read by the instruments designed without it in mind. The territory most responsible for moderating the city's thermal environment exists, paradoxically, in

the deepest part of its analytical blind spot. This is the urban shadow paradox that this chapter names, and that the remainder of this thesis is built to resolve.

That methodological gap is most acute at the level of spatial classification. The Local Climate Zone (LCZ) framework (Stewart & Oke, 2012), the most widely applied morphological-thermal classification system in urban climate research, operates at a typological resolution calibrated to urban neighborhood-scale homogeneity. Applied to the Lecce fringe, it fails at precisely the scale where failure is most consequential: Demuzere et al. (2019) document a classification accuracy of 32% for sparsely built LCZ categories in Mediterranean transition zones, categories that, in the Lecce context, correspond to fringe cells where a heterogeneous mosaic of built fragments, bare soil, dead olive cover, and incomplete infrastructure resists the typological assumption of spatial uniformity. Ren et al. (2019) confirm the pattern across analogous semi-arid fringe contexts: where built, vegetated, and bare-soil patches coexist at sub-100m resolution, LCZ misclassification rates exceed meaningful interpretability. Spacematrix (Berghauser Pont & Haupt, 2010), the morphological density framework developed for Dutch urban contexts, provides a coherent instrument for relating built form to spatial configuration but carries no integration of ecological indicators or thermal outputs, rendering it analytically silent on a fringe where the most important morphological actors are not buildings but dying olive groves, dry-stone walls, and bare karst soil. The FRAGSTATS toolkit (McGarigal & Marks, 1995), widely applied in landscape ecology for patch-level fragmentation analysis, captures the ecological configuration of the agricultural mosaic but cannot be read against Land Surface Temperature (LST) or morphological density without a bespoke integration pipeline. The thermal margin is invisible to these instruments. It registers as noise in urban frameworks and as pattern in landscape frameworks, never as the gradient it is.

Figure 1.3 Classification Resolution at the 100m Cell Scale: LCZ Automated, Actual Fringe Condition, and RUTZ Composite Index

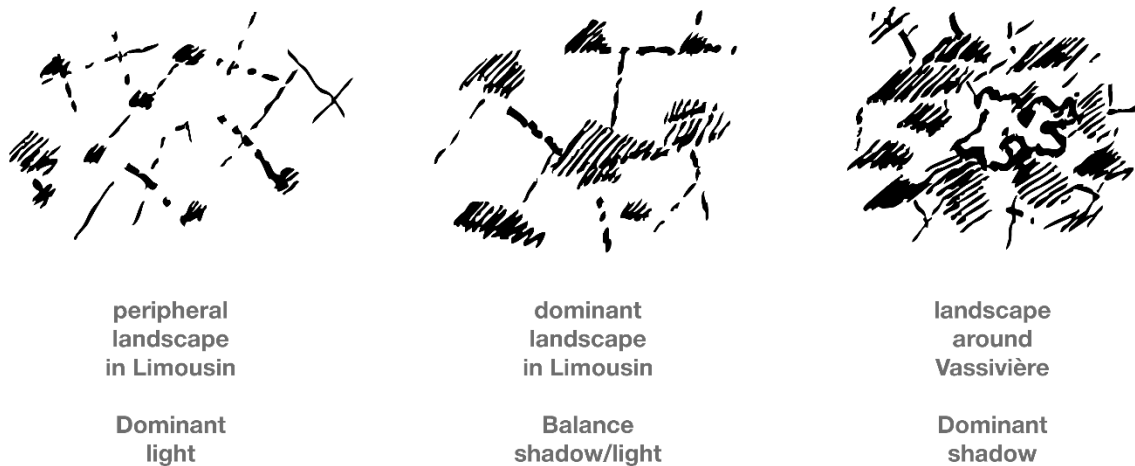


Note. Three-panel comparative diagram at the 100m fishnet cell scale. Left panel: LCZ automated classification collapses the entire cell to a single typology (LCZ 9, Sparsely Built). Centre panel: the actual fringe condition is a mosaic of four coexisting ecologies, olive canopy, exposed karst soil, incomplete villa footprint, and dry-stone wall remnant (dashed). Right panel: the RUTZ composite index resolves the sub-cell thermal gradient from buffer (deep green) to burn zone (dark crimson) that the LCZ framework cannot see. Original illustration by the author.

A generation of thinkers has described what this space is and what it could be, and each of them, in naming it, has confirmed that it has been seen without being measured. Gilles Clément (2004), in his *Manifesto of the Third Landscape*, established that the territories most biologically and thermally productive are those that have escaped the logic of productive optimization governing both city and agricultural interior: the neglected margins, the abandoned edges, in-between territories where biological diversity accumulates precisely because they have not yet been colonized by efficiency. The Shadow — the ecology of repair that this thesis identifies in the Xylella-affected olive fringe of Lecce — is this thesis's Third Landscape. Sordi (2014), tracing the genealogy of landscape urbanism, provides the disciplinary bridge between ecological theory and spatial practice: it is the encounter between landscape architecture and urban planning, she argues, that produces a theoretical infrastructure capable of treating ecology as urban infrastructure rather than its antithesis, the intellectual lineage from which the RUTZ framework descends. The Forested Urbanism tradition argues, further, that the structured integration of vegetated and forested matrices into urban form is a metabolic necessity rather than an aesthetic supplement: the cool belt in the gradient of Lecce that this thesis maps is that matrix in its Salento embodiment. And yet, for all the conceptual richness of this tradition, no quantitative instrument has been built to measure the buffer capacity of these spaces at the resolution the Lecce fringe demands. Clément's own diagrammatic language anticipates this asymmetry before any of his interpreters theorize it. His sketch of concentric urban development shows neglect not as a condition distributed evenly across a territory but as one that compounds with distance from the core: small and incidental

near the urban heart, vast and structurally continuous at the outskirts, the precise spatial logic by which Lecce's peri-urban fringe, rather than its historic center, becomes the territory where the Third Landscape's ecological reservoir, and this thesis's thermal buffer, must be sought (Figure 1.4).

Figure 1.4 *Urban Fabric Expansion and the Production of Neglected Fringe Land*



Note. Adapted from *Manifesto of the Third Landscape*, by G. Clément, 2004, Éditions Sujet/Objet (p. 6). Clément's diagram demonstrates that as urban fabric expands concentrically from a dense core, it generates neglected fringe territories at an accelerating rate: areas of neglect at the urban heart remain small and rare, while those at the periphery become vast and structurally continuous — the precise spatial condition that constitutes the Third Landscape's ecological reservoir.

No instrument currently exists that can map, measure, and classify the rural-urban transition zone of Lecce, its thermal margin, as a graded buffer at the resolution its ecological and morphological complexity demands. The gap is not conceptual; the territory has been named. The gap is instrumental: it has not been measured at the scale its condition requires. This thesis constructs that instrument: the Rural-Urban Transition Zone (RUTZ) Index — a composite spatial instrument integrating morphological, ecological, and thermal indicators into a single cell-by-cell buffer-capacity reading at the resolution of the Lecce fringe's actual complexity. What follows in this thesis is its construction, its calibration to the Salento context, and its first application to the nine municipalities of the Lecce Province peri-urban fringe.

1.3 Research Aims and Objectives

This thesis pursues four operative objectives. They are not a summary of methods; they are spatial commitments, each naming an executable operation on a specific territory, instrument, or dataset that will produce a determinate and verifiable output.

The first objective is to characterize the morphological and ecological gradient of Lecce's rural-urban transition zone through high-resolution GIS analysis of building surface fraction, impervious surface fraction, vegetation vitality, thermal stress indices, and landscape fragmentation across a 100m fishnet grid extending beyond the Tangenziale ringroad, and up to rural and pure agricultural fabrics. This characterization produces the spatial baseline from which all subsequent analysis proceeds: a cell-by-cell reading of the transition zone's thermal and ecological condition at 1 ha resolution, integrating remote sensing data from Landsat 8/9, morphological metrics derived from the 2019 Regione Puglia orthophoto, and fragmentation indices from the FRAGSTATS-equivalent pipeline embedded in the RUTZ Model Builder architecture.

The second objective is to construct the RUTZ Index — a composite spatial index integrating morphological, ecological, and thermal indicators from a ten-layer Model Builder pipeline, capable of classifying the transition zone's buffer capacity at sub-neighborhood resolution and assigning fringe cells to one of three ecological typologies: The Stone, the ecology of deep time and material thermal intelligence; The Fire, the ecology of burn, abandoned unfinished and speculative exposure; and The Shadow/canopy, the ecology of repair and spontaneous ecological recovery. The index operationalizes the theoretical concept of the thermal margin by translating it into a measurable composite metric a single spatial output that carries, in its per-cell value, the combined signal of albedo, NDVI, ISF, BSF, LST, TVDI, SMI, UTFVI, Bare Land Ratio, and normalized patch configuration. These are the instruments of territorial environmental surgery, and their construction and validation constitute Chapter 9 of this thesis.

The third objective is to analyze the demographic structure of the Lecce urban system across the city and its eight surrounding municipalities, examining population density, age cohort distribution, and gender composition and to construct a Heat Risk Index (HRI) from three spatial layers: population density derived from census records, canopy cover and availability cross-checked with the deep learning object detection tools, and average Land Surface Temperature from the July 16 Landsat dataset. The HRI identifies which population classes and which spatial areas of the system are most exposed to excess heat impacts. This demographic analysis and the HRI it produces constitute a distinct analytical strand from the RUTZ Index; they are complementary instruments, each illuminating a different face of the thermal margin's urgency, one spatial and morphological, the other demographic and epidemiological.

The fourth objective is to combine the quantitative RUTZ classification with a critical urban geography reading of the fringe, identifying conflictual coexistences, burn zones, and sites of ecological repair, to position the RUTZ Index as a decision-support instrument legible to both planning policy and design practice, pinpointing the most vulnerable cells that need immediate environmental consideration, strategic incremental interventions, and to demonstrate its capacity to resolve the spatial heterogeneity that LCZ, Spacematrix systematically misclassify in Mediterranean semi-arid fringe contexts.

1.4 Research Questions and Working Hypotheses

The four research questions below are the testable form of the thesis's central proposition. Each is accompanied by a working hypothesis, a theoretically necessary prediction derived from the framework assembled in Chapter 3 and operationalized in Chapters 4 and 5. The hypotheses are not provisional guesses; they are directional commitments that the analysis will confirm, refine, or challenge.

- **Research Question 1 - Thermal Buffer Performance:** To what extent does the rural-urban transition zone of Lecce function as a measurable thermal buffer, and how does its buffer capacity vary across the seasons and across the three defined ecological typologies?

Working Hypothesis 1: The thermal relationship between the three ecologies of Lecce is not fixed. It inverts with the season, and the inversion is the buffer's most significant behaviour. It can be said that during the spring shoulder season, when soil moisture from winter rainfall is still accessible and evapotranspiration functions across the territory, Fire cells (characterised by high impervious and building surface fractions, minimal wall density, and near-zero vegetation index) will register the highest Land Surface Temperature, while Stone cells (characterised by low impervious fraction, the highest wall density in the grid, and the relatively intact karst moisture gradient) will register the lowest. This is the canonical sealed-versus-open thermal differential, consistent with temperate-climate urban heat island theory.

During the summer peak heat season, the ordering will invert. Stone cells, the open karst and dry-stone matrix will register the highest Land Surface Temperature in the study area, because by July, the shallow calcareous soils have exhausted their moisture reserve under the Csa drought regime, exposing the bare limestone substrate to direct solar radiation without the density-shading compensation available in the urban fabric. Fire cells, in contrast, will register LST below the open Stone matrix: not because sealed and built surfaces cool, but because building mass generates mutual shading and the construction materials of the urban edge provide a partial albedo compensation absent from bare karst. Shadow cells, the ecology with the highest vegetation index and the most retained canopy moisture will demonstrate the strongest summer cooling capacity of the three, precisely because they are the cells where the evapotranspirative mechanism is least compromised and behaving normally.

This seasonal inversion, Stone hottest in summer, Fire hottest in spring, Shadow consistently performing closest to its theoretical buffer potential confirms that the buffer function of the transition zone is not a fixed property of its land cover but a seasonally contingent performance, structured by the Csa climate's progressive stripping of moisture from the open landscape. It is this inversion, not a static cool/hot dichotomy, that the RUTZ Index is designed to detect and that planning intervention must be designed to address.

The hypothesis will be tested against the four-year, twelve-scene thermal record in Chapter 7.

- **Research Question 2 - Classification Framework Adequacy:** What do the documented limitations of existing spatial classification systems, Local Climate Zones, Spacematrix, and FRAGSTATS-based fragmentation analysis reveal about their capacity to resolve the morphological and thermal complexity of Lecce's peri-urban fringe, and does a composite index built on adapted versions of their component logics succeed where the source frameworks, applied independently, do not?

Working Hypothesis 2: The literature will confirm that standard LCZ classification systematically misclassifies Lecce's fringe cells particularly the sparsely built (LCZ 9) and agricultural mosaic (LCZ D) categories that together encompass most of what the RUTZ framework designates as Stone, Shadow, and the lower bands of the peri-urban gradient because the LCZ framework's neighborhood-scale homogeneity assumption cannot resolve a heterogeneous mosaic of built fragments, bare karst, declining vegetative cover, and vernacular dry-stone infrastructure at 100-meter resolution. Rather than reproducing this failure by applying LCZ, Spacematrix, or FRAGSTATS directly, the RUTZ Index integrates an adapted fragmentation stack, morphological density metrics, and ecological composition into a single continuous score. Its capacity to predict the independent thermal record held out of its own construction (section 4.5, tested formally in Chapter 9) will demonstrate a classification coherence that the source frameworks, evaluated in isolation, cannot achieve in this morphological context.

- **Research Question 3 - Population Heat Exposure:** Which populations within the Lecce urban system are most exposed to heatwave risk, and where does the convergence of high population density, low tree cover, and elevated Land Surface Temperature concentrate that exposure across the city and its satellite towns?

Working Hypothesis 3: The Heat Risk Index — a composite of three normalized inputs applied at the census-section scale across 1,763 sections covering the nine study municipalities will reveal that heat exposure is not distributed proportionally to population size but concentrates structurally in the satellite towns rather than the historic urban core. The three inputs read different dimensions of the same vulnerability: population density captures who is exposed; the Tree Cover Density lacking percentage captures what protection is absent; and Land Surface Temperature captures the thermal intensity of that exposure. Their sum, normalized across the study area, produces a per-section composite that reflects not only where people live but where they live unprotected, in the hottest terrain.

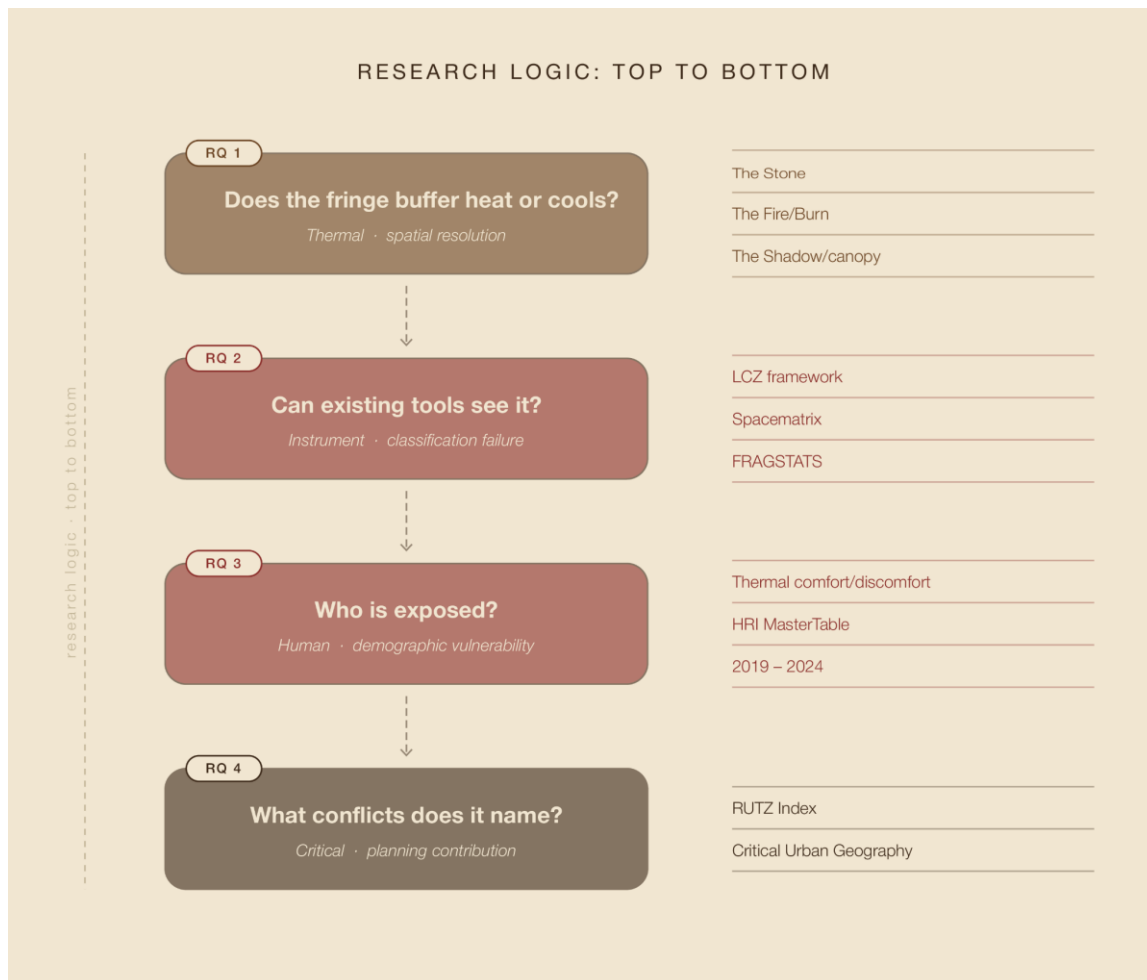
The hypothesis predicts that the satellite municipalities, in particular those with the highest surface temperatures and the lowest tree cover fractions in the study area will return the highest per-section Heat Risk Index scores, despite carrying smaller total populations than

the city of Lecce itself. This is because the inverse of the reverse Urban Heat Island dynamic identified in section 2.2.2 operates at the population scale: the historic urban core of Lecce, whose Pietra Leccese fabric moderates surface temperature and whose relatively compact density disperses the thermal load, will register lower per-section HRI mean values than the satellite towns where open or peri-urban morphologies expose populations to higher surfaces temperatures with negligible tree cover. The HRI makes a planning vulnerability legible, that aggregate population statistics and administrative zoning maps both conceal: that the settlements most exposed to heatwave risk are not necessarily the most populous but those where population density meets maximum thermal exposure in the absence of any canopy buffer. This hypothesis will be tested in Chapter 8, where the HRI results are mapped, interpreted, and cross-referenced with the age-structure and dependency-ratio data to identify which specific demographic cohorts bear the highest concentrated risk within the highest-scoring census sections.

- **Research Question 4: Critical Urban Geography Reading:** What conflictual coexistences are legible in Lecce's peri-urban fringe cells through critical urban geography observation, and how do these spatial conflicts, the abandoned industrial shed against the masseria, the dead olive grove against the villa block, the dry-stone wall against the sealed road surface, constitute the three ecological systems that the RUTZ Index classifies qualitatively and quantitatively?

Working Hypothesis 4: The RUTZ Index's composite metric signature in each 100m cell will be interpretable not as a point on a neutral continuum between urban and rural, but as a record of one of three co-present ecological logics, Stone, Shadow, and the ecology of Fire, each producing a distinctive and internally coherent pattern of ISF, NDVI, LST, and fragmentation values that corresponds to a legible spatial conflict visible at the scale of the street, the plot, and the field boundary. The quantitative classification and the critical territorial observation will be mutually verifying: where the index assigns as the Ecology of Fire, conflictual coexistence between sealed expansion and ecological residue will be visually confirmed; where the index assigns ecology of stone, material thermal intelligence will be thermally registered in degrees Celsius per cell.

Figure 1.5 Research Logic Flow: Four Research Questions and Working Hypotheses



Note. Vertical logic-flow diagram of the thesis's argumentative dependency structure. Original illustration by the author.

1.5 Significance: Bridging Architectural Technology and Spatial Data Science

The significance of this thesis operates at three scales: theoretical, methodological, and planning, and finds its center of gravity at their intersection.

Theoretically, this thesis introduces the RUTZ Index as the first composite spatial instrument designed and calibrated specifically to measure the buffer capacity of a Mediterranean semi-arid peri-urban fringe at sub-neighborhood resolution. It extends the theoretical lineage established by Pijpers van Esch (2016), who demonstrated that urban morphology is analytically translatable into climate-responsive design intelligence, from the scale of the individual neighborhood to the scale of the entire fringe gradient. It operationalizes, for the first time quantitatively, the ecology-reading method that Banham (1971) demonstrated qualitatively for Los Angeles: the thesis gives the three ecologies of Lecce their measuring instrument. And it proposes the thermal margin of the concept, articulating the peri-urban interface as a politically and metabolically constituted climate

condition rather than a neutral spatial category as a conceptual contribution to the scholarly vocabulary of climate-responsive planning in Mediterranean contexts.

Methodologically, the thesis delivers a fully reproducible Geospatial data analysis pipeline, documented in a spatial geodatabase for highest consistency across the project, integrating indicators of spectral and morphological index stack, a deep learning object detection layer, and a Model Builder composite index architecture. Every processing step is documented for transfer to comparable Mediterranean fringe contexts: the province-scale analytical framework is directly applicable to Bari, Taranto, Brindisi, and Reggio Calabria, all of which share the Csa climate regime, the peri-urban fragmentation pattern, and the planning policy deficit that defines the Lecce case. The pipeline's combination of Spacematrix-derived morphological metrics, FRAGSTATS-equivalent landscape fragmentation indices, and thermal and vegetation spectral indices constitutes an instrument architecture that has not previously been assembled for Mediterranean fringe analysis at this resolution.

From the planning perspective, the RUTZ Index and the Heat Risk Index constitute two distinct but complementary contributions to practice. The RUTZ Index provides a decision-support instrument capable of mapping the fringe's buffer capacity cell by cell, calibrated to the resolution demands of the Piano Urbanistico Generale (PUG) and the Piano Paesaggistico Territoriale Regionale (PPTR). The HRI separately identifies which populations bear the greatest exposure to heatwave conditions, a demographic lens that RUTZ's morphological classification cannot supply on its own. Together, these instruments give the PUG and the PPTR the spatial vocabulary they currently lack: the capacity to name, protect, and design for the conflictual coexistences that official zoning maps render as undifferentiated "agricultural zone" or "transformation area" while the satellite data records 42.25 °C and rising.

This thesis occupies the intersection of Architectural Technology Engineering, Urban and Regional Planning, and Critical Urban Geography along with geospatial data science practices, and that intersection is not an institutional compromise between disciplines. It is the only location from which the thermal margin can be seen. Thermal physics explains the 42.25 °C figure. Landscape ecology explains the NDVI collapse. Urban morphology explains the ISF accumulation. Critical urban geography explains why the abandoned industrial shed is beside the masseria, why the villa block is beside the dead olive grove, why the dry-stone wall is bisected by the sealed road surface. And the tools help us to scrutinize and observe what is within. No single discipline sees all four at once. This thesis does.

1.6 Scope and Delimitations

The spatial scope of this thesis is the peri-urban fringe of the Province of Lecce, analyzed across nine municipalities: Arnesano, Cavallino, Lecce, Lequile, Lizzanello, Monteroni di Lecce, San Cesario di Lecce, San Pietro in Lama, and Surbo. The study area is defined by

the Grid Limit in the Lecce Prime geodatabase at UTM Zone 34N, covering the continuous transition zone gradient connecting the urban core of Lecce to its agricultural hinterland. The primary analytical unit is the 100m fishnet cell, a 1-hectare grid at which morphological metrics derived from parcel-level cadastral data, spectral indices derived from 10–30m satellite imagery, and fragmentation indices derived from the landscape patch structure can be integrated without information loss. A 200m × 4000m peri-urban transect provides a cross-sectional reading of the gradient for visualization, comparative analysis, and incremental prototype strategy proposals.

Figure 1.6 Study Area: Nine Municipalities of the Lecce Peri-Urban Fringe, Province of Puglia, Italy



Note. Study boundary (white dashed line), 100m × 100m analytical fishnet grid (8,625 cells, 1 ha each), nine municipality administrative boundaries (thin dark lines), and 200m × 4,000m peri-urban gradient transect corridor (orange line). Inset: location of the study area within the Province of Lecce and the Italian peninsula. The nine municipalities are Arnesano, Cavallino, Lecce, Lequile, Lizzanello, Monteroni di Lecce, San Cesario di Lecce, San Pietro in Lama, and Surbo. Projection: EPSG:32634, WGS 84 / UTM Zone 34N. Basemap: Esri World Imagery (Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community). Administrative boundaries: Istituto Nazionale di Statistica (ISTAT).

The temporal scope is defined by two anchored datasets. The morphological baseline is the OpenStreetMap Geofabric building datasets and the 2019 Regione Puglia high-resolution orthophoto (approximately 0.5m spatial resolution), from which building surface fraction, impervious surface fraction, and tree canopy extent are derived using

object detection deep learning methods cross-checked across the study area. The primary thermal analysis dataset is the July 16 Landsat 8 acquisition, the date on which heatwave conditions produced the highest LST variability across the study area in the available record, making it the most diagnostically informative single acquisition for fringe thermal analysis. The socio-demographic vulnerability analysis draws on the HRI Master Table, which provides municipality-scale health risk and demographic data for the period 2019–2024 across the nine municipalities.

Three delimitations define the boundaries of what this thesis can and cannot claim, and each is a principled intellectual decision rather than a methodological concession. Building height data is not available at province-wide resolution from open Italian cadastral or regional sources; Sky View Factor and three-dimensional morphological analyses, which would add a vertical dimension to the thermal buffer characterization, are accordingly excluded. This exclusion locates the horizontal-plane RUTZ classification as the analytical foundation from which a doctoral-continuation 3D analysis can proceed; it is a staging decision, not a gap. Nocturnal Land Surface Temperature is excluded because insufficient Landsat thermal night-pass coverage is available at the spatial and temporal resolution required for a statistically robust fringe-gradient analysis; this limitation does not compromise the thesis's central argument, which is anchored in daytime heatwave conditions, but it does identify nocturnal cooling dynamics as a documented research continuation priority. Qualitative field interviews with residents, farmers, and planning authorities fall beyond the scope of a morphological-quantitative study; the planning implications drawn in Chapter 10 are grounded in spatial evidence and the critical urban geography reading method, not in reported stakeholder positions.

1.7 Thesis Structure: Reader's Map

Part I of this thesis, the Foundations, builds the intellectual territory across three chapters. Chapter 1 has established the crisis: the thermal margin of Lecce is burning, is measurable, and is without a planning instrument capable of reading it at the resolution its complexity demands. Chapter 2 surveys the scholarship from which the thesis draws: the literature on peri-urban dynamics, morphological-thermal analysis, landscape ecology, and Mediterranean climate vulnerability that has separately produced the conceptual tools this thesis assembles into a coherent analytical architecture. Chapter 3 translates those tools into owned instruments; the Theoretical Framework chapter in which the five research pillars are constituted as an analytical architecture, the RUTZ logic is defined as a conceptual position, and this thesis's location within the field is staked. The reader leaves Part I knowing what the problem is, what the field has argued, and what this thesis brings to the encounter.

Part II, the Methodology, runs across Chapters 4 and 5. Chapter 4 designs the research: it formalizes the spatial scope, defines the RUTZ Index's constituent indicators, and

establishes the ontological position from which quantitative remote sensing and critical urban geography can be practiced as a single, methodologically coherent inquiry. Chapter 5 executes the spatial data workflow: the ten-layer Model Builder pipeline, the deep learning object detection tool, the fishnet cell compilation, and the statistical procedures for testing the four working hypotheses. Every methodological choice made in Part II traces directly to the theoretical decisions made in Part I. Nothing in the pipeline is optional; every indicator is there because the RUTZ framework demands it.

Part III is dedicated to the Salento Case — which develops across Chapters 6, 7, and 8 as a mounting territorial argument. Chapter 6 characterizes the peri-urban gradient through the Three Ecologies lens — The Stone, The Fire, and The Shadow — reading the RUTZ cell data as a portrait of morphological and ecological conditions across the nine municipalities. Chapter 7 reads the thermal evidence: Land Surface Temperature distributions, urban thermal comfort anomalies, the spatial logic of the burn zone, and the thermal differential between the Stone’s limestone intelligence and the Stone’s exposed fringe surfaces. Chapter 8 analyzes the demographic structure of the Lecce urban system, including population density, age class distribution, and gender composition across the city and its eight satellite towns and constructs the Heat Risk Index, mapping where the convergence of high population density, low tree cover, and elevated Land Surface Temperature concentrates exposure most severely among heat-vulnerable cohorts. These three chapters do not summarize independent analyses; they build a single, cumulative case for the thermal margin’s urgency.

Part IV, the Synthesis, arrives in Chapters 9, 10, and 11 with the thesis’s original contributions. Chapter 9 constructs the RUTZ Index formally, documents its validation, and tests the four working hypotheses against the spatial evidence produced in Part III. Chapter 10 operationalizes the index as a planning instrument: three design prototypes and policy scenarios adjusted to the Stone preservation, the Fire intervention, and the Shadow ecological repair, each with recommendations legible to PUG and PPTR planning contexts. Chapter 11 reflects on what the RUTZ framework changes in the way the Lecce fringe is seen, measured, and governed and what research makes it possible that was not possible before.

The transition zone is not a residual space between the city and its agricultural hinterland. It is a thermal membrane, a biological corridor, and a planning instrument waiting to be named. This thesis names it.

Chapter 2

CHAPTER 2 – Literature Review

2.1 The Theory of the 'In-Between' — Defining the Peri-Urban Buffer

2.1.1 Defining the Peri-Urban Buffer: Beyond the Urban-Rural Binary

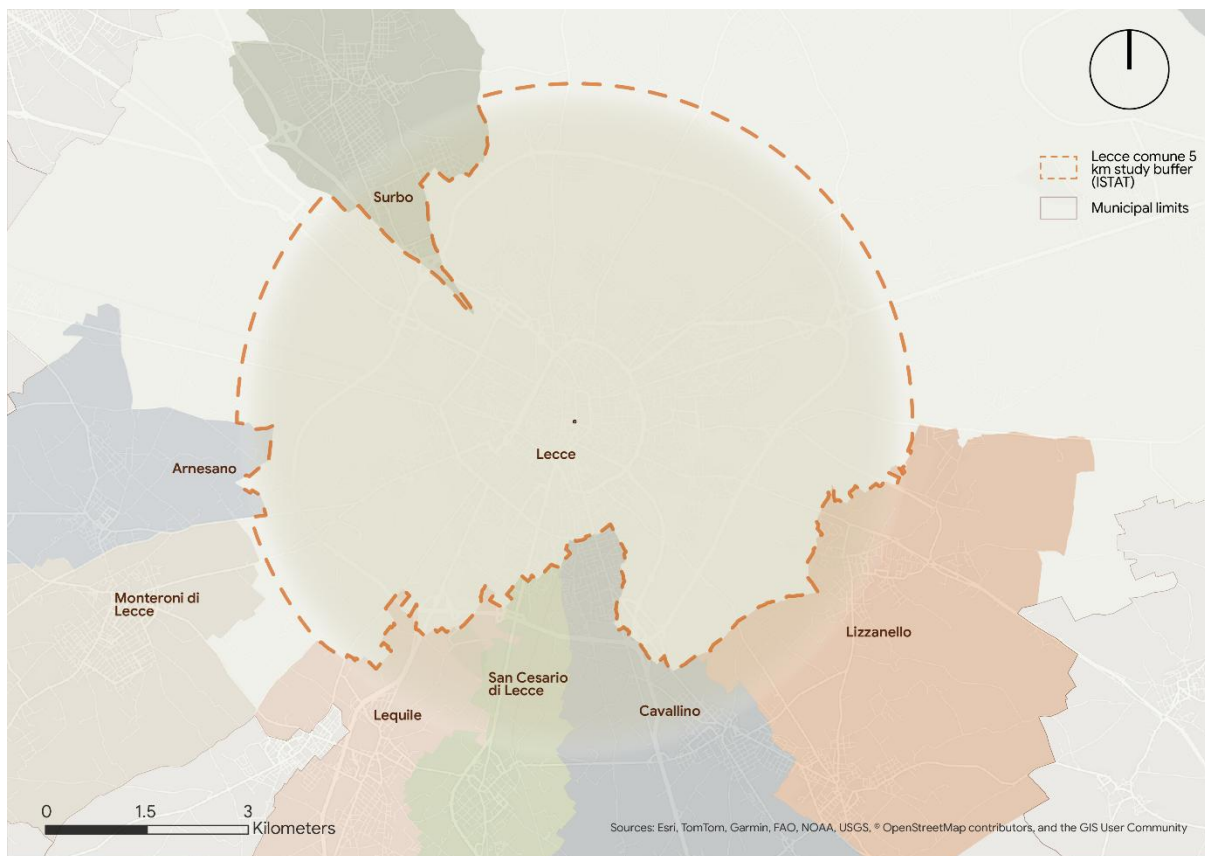
The binary map is a fiction. For decades, planning operated on the assumption that the city stops where the country starts, drawing jurisdictional lines as if they were ecological ones, a Cartesian convenience that served administrative simplicity, statistical legibility, and the modernist appetite for sharp edges, but never described how a Mediterranean territory actually behaves. The binary persists less because anyone defends it intellectually and more because it is institutionally cheap: census categories, cadastral inheritance, and zoning ordinances all depend on the line being drawable. The supposed boundary between urban and rural is, in the Salento as elsewhere, a thick, porous membrane through which heat, water, capital, and bodies move in both directions. To treat it as a line is to misread and misunderstand the metabolism of the city itself, and to forfeit the design vocabulary needed to act on that metabolism.

What development planners began in the late 1990s to call the Peri-Urban Interface (PUI) is less a place than an operative process. Allen (2003), drawing on Tacoli's (1998) earlier survey of rural-urban interactions, which Allen synthesizes as *footloose processes* (Allen, 2003, p. 136), and names the fringe an "*uneasy phenomenon*", a zone of indeterminate in-betweenness where the spatial logic of the city (accumulation, sealing, densification) collides with the ecological logic of the periphery (permeability, seasonality, biological ecosystems). The shift from boundary line to thick surface is not a rhetorical decoration; it is an epistemological demand. A line can be drawn on a map. A surface must be measured, monitored, and read for the gradients that move across it. For Lecce, the consequence is concrete: the microclimatic health of the historic core depends on whether the surrounding membrane breathes normally or suffocates the other way. Reframing the fringe as a process, not as a residual geometry between two pre-defined territories, is the precondition for treating it as a designable system.

Because the PUI ignores administrative borders, governance fails to interact with it. Allen (2003, pp. 138–139) describes the institutional landscape of the fringe as a converging field of overlapping sectoral remits, a condition he dissected across consecutive analytical sections covering the ecological-spatial, socioeconomic, and institutional dimensions of fringe governance, in which water provision falters, waste management defaults, and land-use rules drift between municipalities that are individually too small or too rural-leaning, or too urban-leaning, to manage what is in front of them. Wandl and Magoni (2017) sharpen this diagnosis by naming the specific functional conflict it produces: the global agro-industrial "right to farm" competes directly with incoming residents' "right to a good life" on shared terrain, and the planning system, calibrated to single-use logic, has no instrument

for ruling on that competition. In the Salento, the fragmentation is institutional and concrete at once. Land-use jurisdiction is split between the Comune di Lecce, the Provincia di Lecce, and the Regione Puglia, with the Piano Paesaggistico Territoriale Regionale operating at one scale, the Piano Urbanistico Generale at another, and the surrounding municipalities (Surbo, Arnesano, Monteroni di Lecce, Lequile, San Cesario di Lecce, Cavallino, and Lizzanello) each asserting independent zoning. Centennial olive groves — the territory’s most efficient evapotranspiration and cooling engines have fragmented into low-albedo residential patches that trap rather than radiate the summer load. The blind spot of policy becomes the hot spot of the territory. This is the precise condition this thesis names the *Thermal Margin*: a border space where climatic variation and infrastructural marginality intertwine to produce hybrid forms of vulnerability that no rural or urban planning tradition, taken alone, can address (see Figure 2.1).

Figure 2.1 Administrative Jurisdiction Overlay: Lecce and the surrounding municipalities within the Peri-Urban Buffer Zone.



Note.

Municipal boundaries of seven comuni circostanti intersecting the Lecce comune 5 km study buffer (ISTAT): Surbo (north), Arnesano (west), Monteroni di Lecce (south-west), Lequile (south-south-west), San Cesario di Lecce (south), Cavallino (south-east), and Lizzanello (east). The dashed boundary line demarcates the Lecce comune boundary with a 5 km study buffer applied (source: ISTAT commune dataset, Lecce selection); solid outlines indicate adjacent municipal limits (ISTAT). The overlay exposes the jurisdictional fragmentation structuring land-use governance in the fringe: no single planning instrument holds authority across the full buffer extent. Cartographic data: ISTAT municipal boundaries; basemap: Esri Light Gray Canvas. Author’s own cartography.

Allen (2003, p. 143) reads the fringe as a system of multidirectional flows: people, production, commodities, capital, information, natural resources, and waste moving

between rural production regimes and urban functions in patterns that, after Douglass (1998), are either mutually reinforcing or truncated (*Figure 2.2*). The framework is useful but incomplete in one specific way that this thesis takes as a point of departure. These conduits also carry thermal energy. Where the rural matrix is intact, a continuous canopy, a permeable soil column, a dry-stone-walled grid that channels moisture rather than runoff, latent heat flux through evapotranspiration cools the air column above the territory and tempers the air arriving at the urban edge. Where the matrix is severed by impervious arteries, the same flows now deliver sensible heat into the urban core, and the city's *ecological footprint* (Allen, 2003, p. 138, citing Rees, 1992) stops being merely a metabolic claim on a hinterland and becomes a thermal liability that returns to the city as elevated nocturnal temperature. The empirical signature of this is already legible in Lecce. Pappaccogli et al. (2024), monitoring six weather stations across the city over four years, find that stations surrounded by green areas or located in suburban settings record the lowest Urban Heat Island Intensity (UHII) values, while stations embedded in dense urban fabric record the highest, a pattern that intensifies sharply during heatwaves, when the densest urban station registers a 2.60 °C average UHII by air-temperature measurement, approximately 3.5 times the 0.74 °C UHII simultaneously recorded by Land Surface Temperature (LST) analysis across the same network, a fourfold divergence that reflects the respective sensitivities of each method to the thermal mass of sealed fabric versus the radiative dynamics of the vegetated fringe (Pappaccogli et al., 2024; see *Figure 2.3*). The diagnostic question is no longer whether the city extends its ecological footprint into the hinterland — every city does but whether the hinterland still has the morphological capacity to absorb the city's thermal load without collapsing into a dry-island regime.

Figure 2.2 Multidirectional Rural–Urban Flows as a Metabolic System.

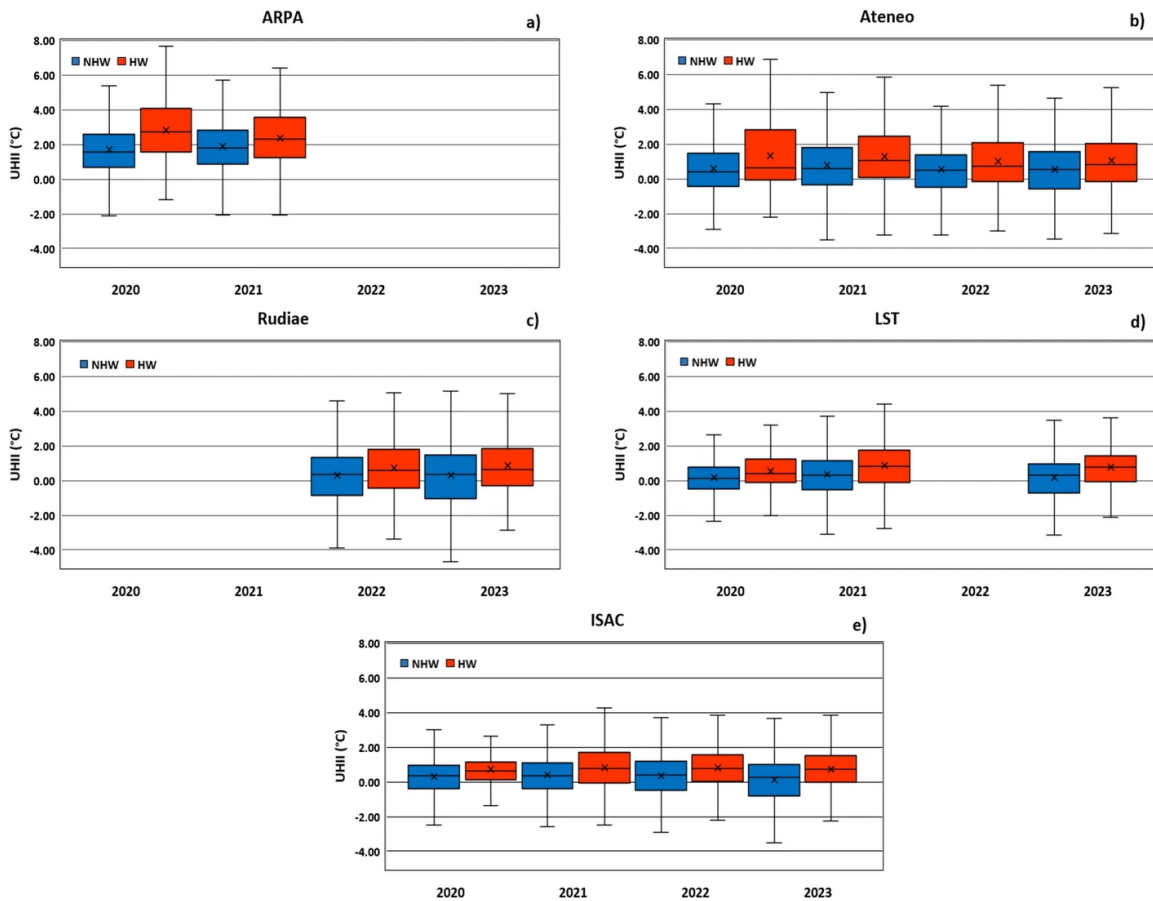
FIGURE 02 · SCHEMATIC FLOW DIAGRAM

Eight categories of rural-urban exchange in a Mediterranean peri-urban territory



Note. Schematic of the systemic exchange of people, production, commodities, capital, information, natural resources, and waste between rural production regimes and urban functions. Read against the Salento case, the diagram exposes a missing arrow: the thermal flux that travels along the same conduits, cooling the urban core when the rural matrix is intact and overheating it when the matrix is severed. Adapted from “Environmental planning and management of the peri-urban interface: Perspectives on an emerging field,” by A. Allen, 2003, *Environment and Urbanization*, 15(1), p. 143 (Figure 2 in original), after Douglass (1998); Allen extends the original framework by adding the natural-resources and waste-and-pollution rows.

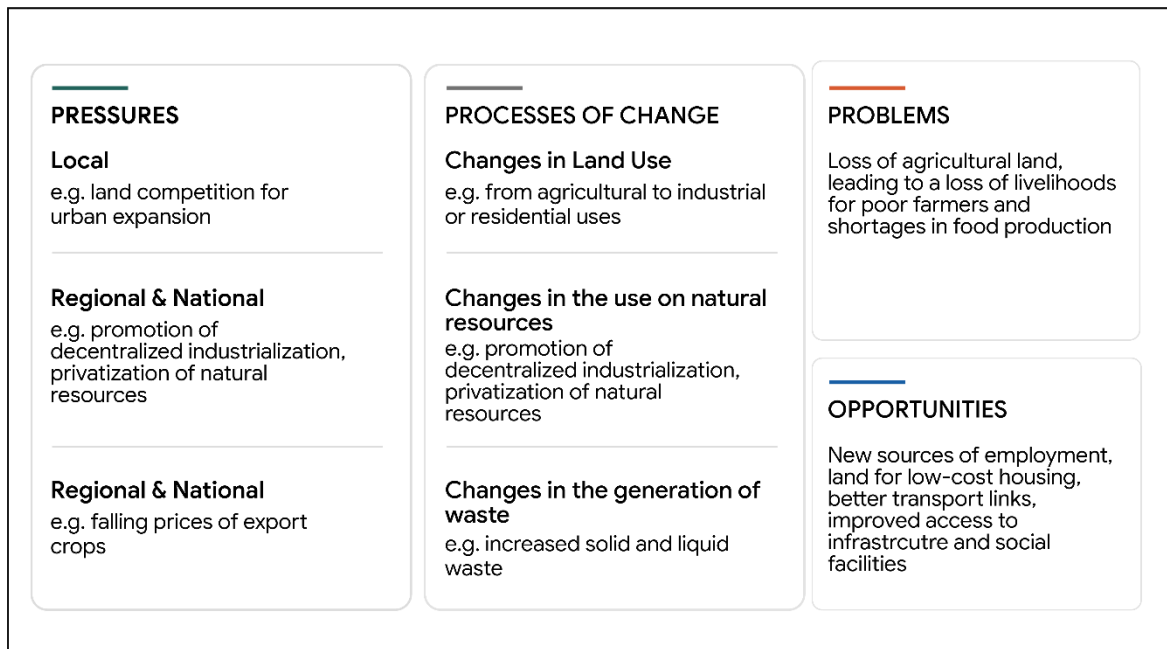
Figure 2.3 Urban Heat Island Intensity Under Heatwave and Non-Heatwave Conditions, Lecce.



Note. Box plots of UHI values from six weather stations across Lecce's urban-rural gradient, contrasting heatwave (HW) and non-heatwave (NHW) periods. The figure confirms the 2.60 °C peak UHI at the densest urban station during HW conditions, against 0.74 °C as derived by land surface temperature (LST) analysis over the same network, a fourfold divergence that anchors the empirical claim that the city's thermal liability intensifies precisely when the fringe buffer is most needed. From "Dynamics of urban heat island intensity in Lecce, Italy: Seasonal, diurnal and heat wave influence," by G. Pappacogli et al., 2024, *Bulletin of Atmospheric Science and Technology*, 5, 8. Copyright 2024 Springer Nature.

These flows do not move in equilibrium. They are pushed by multi-scalar pressures, local competition for development land, national decentralization and privatization regimes, and international commodity-price volatility that converge on the fringe as a single transformative surface (Figure 2.4). Allen (2003) treats the resulting processes of change as dual-natured, generating both crisis (loss of agricultural land, food-production shortfall, displacement of poor farmers) and opportunity (low-cost housing, transport linkage, infrastructural access). In the Salento, that dualism collapses asymmetrically. The casualty side dominates: fragmented dry-stone networks, abandoned groves, mineralized roadside parcels, unfinished construction sites, and the speculative residential infill that follows. Gallent and Shaw (2007) explain why the planning response has been inadequate: traditional spatial planning treats the fringe as something to be contained (rigid green belts, defensive zoning) rather than designed, producing instruments that are reactive at best and that mistake the absence of urban form for the absence of planning needs. Strategic Environmental Planning and Management (Allen, 2003, p. 145) becomes less a methodology than a diagnosis. Without a cross-sectoral, incremental intervention model, the buffer is wasted before it is recognized, and thus, Salento's climate liability deepens parcel by parcel.

Figure 2.4 Processes of Change in the Peri-Urban Interface.

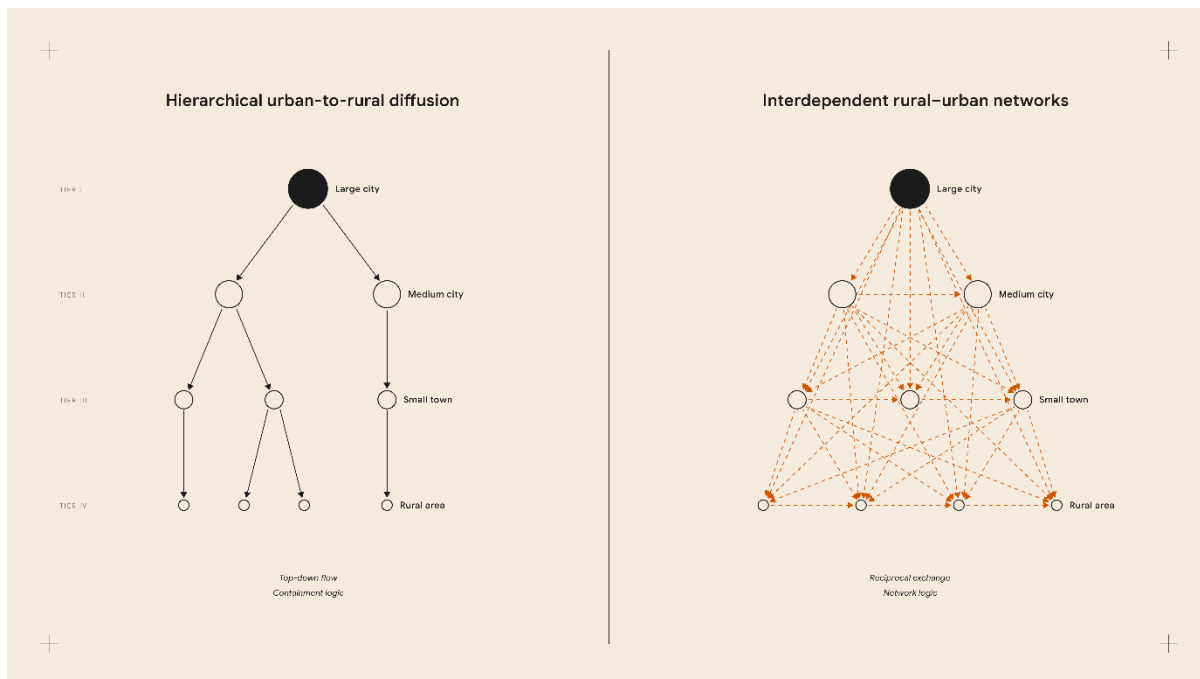
**Note.**

Allen's mapping of pressures (local, national, international), processes of change (land-use, natural-resource use, waste accumulation), and the dual outcome of problems and opportunities. In the Salento, the dual character collapses: the speculative-residential side dominates while the integrative side (affordable housing, infrastructural access) underdelivers, a structural asymmetry that produces fragmentation rather than balance. Adapted from "Environmental planning and management of the peri-urban interface: Perspectives on an emerging field," by A. Allen, 2003, *Environment and Urbanization*, 15(1), p. 143 (Figure 3 in original).

The gap between containment logic and design logic is not merely rhetorical: Douglass (1998, p. 14) makes it structural. His Figure 1 contrasts two territorial paradigms side by side. On the left, the hierarchical urban-to-rural diffusion model, in which the metropolis broadcasts its logic outward in attenuating waves until it meets the inactive edge of the rural periphery: a model that assumes a direction of influence (city toward countryside) and a terminal boundary where influence stops. On the right, the interdependent regional network model, in which rural and urban nodes are connected by reciprocal flows — labor, capital, food, ecological services that sustain both poles simultaneously and that are disrupted only when the network is severed, not when the city grows. The first paradigm is the conceptual architecture of the green belt and the containment ordinance: it requires the line to function. The second is the architecture of what this thesis calls the thermal buffer: a territory in which the rural matrix is not a passive receiver of urban influence but an active metabolic partner, its evapotranspiration engines tempering the air column above the fringe and delivering cooled air to the urban edge. Lecce, in its current condition, occupies precisely the pathological gap between the two models: the hierarchical paradigm has broken down, the containment line no longer holds — without the network model having emerged to replace it. The Tangenziale is the spatial hinge of that failure: an arterial

infrastructure built on diffusion logic that now delivers sensible heat, not a cooling signal, into the city it was meant to serve (Figure 2.5).

Figure 2.5 Hierarchical Urban-to-Rural Diffusion Versus Interdependent Rural–Urban Networks



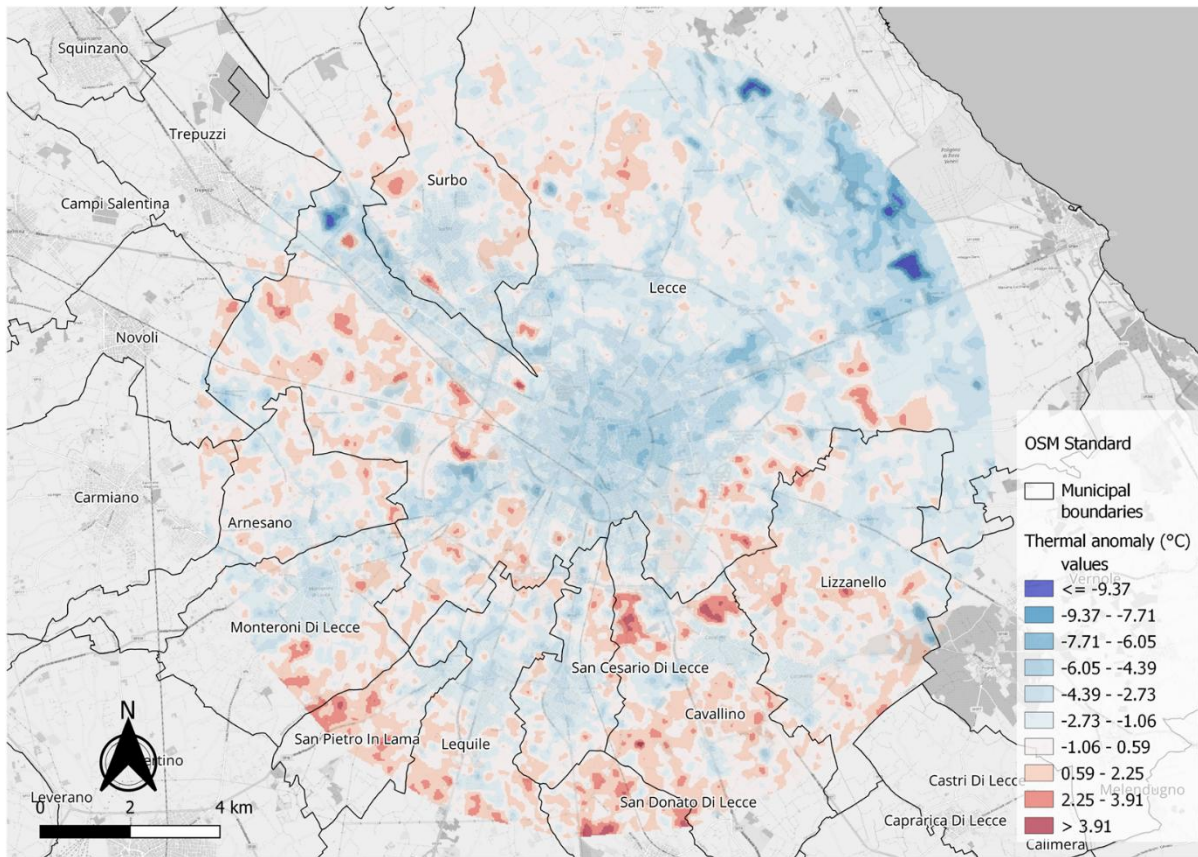
Note.

Douglass's structural contrast between the containment-based hierarchical diffusion paradigm (left) and the reciprocal regional network model (right). In the Salento, the current territorial condition corresponds to the breakdown of the first model without the consolidation of the second; the Tangenziale corridor operates as the spatial hinge of that failure, converting a potential network node into a thermal barrier. Adapted from "A regional network strategy for reciprocal rural–urban linkages: An agenda for policy research with reference to Indonesia," by M. Douglass, 1998, *Third World Planning Review*, 20(1), p. 14 (Figure 1 in original)—copyright 1998 Liverpool University Press.

The Salento gives this abstraction a name. Indovina (1999), in his foundational position paper *La città diffusa: cos'è e come si governa*, argues that the diffuse city is not an autonomous form but the evolution of pre-existing patterns of territorial occupation, an *urbanized countryside* (*campagna urbanizzata*) in which urban functionality and social relations colonize a landscape that retains the cadastral grain of the agricultural matrix. Donadieu (2013) reframes the same condition from the opposite side, naming it *campagna urbana* and treating the apparent oxymoron, the once-impossible coupling of two antithetical terms as a landscape in which *indizi di nuove ecologie* (signs of new ecologies) emerge between territory and society, partly dependent on urban culture and partly resistant to it. Viganò, Cavalieri and Corte (2018) push the framing further with their *Horizontal Metropolis* thesis: the dispersed Veneto–Salento condition is not a degraded urbanism but a different urbanism, one in which density is replaced by proximity and the metropolis is a horizontal ecology rather than a vertical concentration. Read together, the three framings refuse a moralized narrative of sprawl. They identified a hybrid productive landscape whose collapse, when it occurs, is structural rather than aesthetic. Soil sealing eliminates evapotranspiration parcel by parcel. The car becomes the metabolic pump, demanding a

dense network of low-albedo asphalt that absorbs almost all incoming shortwave radiation and re-emits it as longwave heat for hours after sunset, displacing the comparatively higher-albedo agricultural soils and the limestone substrates that once moderated the air column. The biophysical signature of this collapse is unusual. De Razza et al. (2024), mapping land surface temperature across Lecce during the July 2022 heatwave (Landsat-8, 24 July 2022), identified a *reverse urban heat island* phenomenon in which the historic Pietra Leccese core is a thermal anomaly: urban impermeable surfaces (40.32 °C mean) sit below sparsely vegetated peri-urban soil (42.25 °C mean), and across the wider study area urban areas register up to 11 °C lower LST than the surrounding rural fringe; the absolute LST minimum of 31.44 °C is recorded at an exposed white-limestone (calcarenite) quarry, confirming the regulating role of high-albedo Pietra Leccese material (see *Figure 2.6*). The inversion depends on the high albedo of the limestone and is actively eroded as the rural matrix mineralizes. The urban heat island, in this geography, is no longer a centralized peak. It becomes a distributed, territory-wide thermal plateau in which the historic core remains a cool island only because its material constitution still resists what the fringe has become. *Figure 2.7* renders this transformation as a structural diagram: the left panel shows the territory's metabolic logic when the rural-to-urban gradient is intact, a buffer that absorbs, filters, and tempers the thermal load before it reaches the urban core; the right panel shows what the same gradient produces when the buffer has been severed — a thermal plateau in which the fringe amplifies rather than regulates the heat the city generates, and in which the limestone core survives as a cool island not by design but by material intelligence that governs the built fabric.

Figure 2.6 Land Surface Temperature Anomaly and Reverse Urban Heat Island, Lecce, 2022 Heatwave.



Note. LST thermal anomaly map of Lecce during the July 2022 summer heatwave event (image of 24 July 2022), derived from Landsat-8 imagery. The colour gradient reveals the reverse-UHI pattern: the historic Pietra Leccese core appears as a cool island (darker tones) against the warmer rural fringe and peri-urban agricultural matrix (lighter tones). From “Mapping urban heatwaves and islands: The reverse effect of Salento’s ‘white cities,’” by S. De Razza et al., 2024, *Frontiers in Earth Science*, 12, 1375827.

A counter-reading is necessary here, because the optimistic Donadieu/Viganò framing risks reading new ecologies into a landscape that, in places, has none. Augé (1995) describes non-places — the supermarkets, ring-roads, logistics sheds, and waiting rooms of supermodernity as spaces that produce neither identity nor relation, only solitude and similitude. Significant tracts of the Città Diffusa along Lecce’s Tangenziale and the SS613 corridor function precisely as Augé’s non-places: the unmanned petrol station, the discount supermarket parking apron, the unfinished housing estate enclosed by a chain-link fence. The argument of this thesis is not that the Salento fringe is uniformly a productive hybrid (Donadieu) or uniformly a constellation of non-places (Augé). It is that the fringe contains both, in fine-grained alternation, and that the conventional planning instruments cannot distinguish between them at the resolution that matters. The diagnostic problem and the design problem are the same problem, posed at different scales.

Iaquinta and Drescher (2000) refuse to treat the peri-urban as a monolith. From a socio-demographic and migration-history standpoint they identified five typologies — *Village PU* (traditional rural settlements undergoing socio-cultural urbanization through remittance, media, and consumption patterns), *Diffuse PU* (urban functions scattered through an agricultural matrix without a center), *Chain PU* (linear development along infrastructure

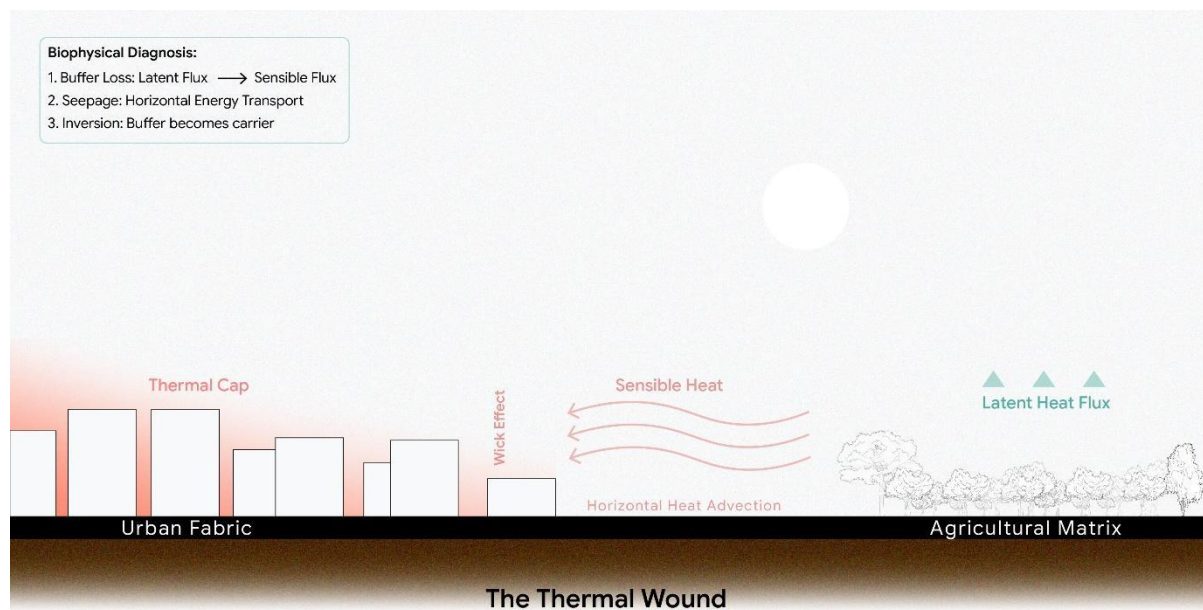
corridors), *In-Place PU* (rural land consumed whole by an advancing urban front), and *Absorbed PU* (former rural areas fully integrated into the urban fabric but retaining cultural and ecological vestiges). The typology is socio-spatial, not biophysical, and it refuses the assumption that “*rural*” is the opposite of “*urban*”. Two of the five overlap aggressively in the Lecce region. The *Diffuse* model maps onto the regional diffuse urban condition identified by Indovina and Viganò. The *In-Place* model describes what happens at Lecce’s expanding eastern and southern edges: the urban front does not pass through the agricultural matrix, it consumes it whole, leaving ancient olive groves and dry-stone wall networks trapped as captured rurality inside an asphaltic context that was not there a generation ago. The land is used like a city and managed like a farm or increasingly, not managed at all. This double bind, more than any single phenomenon, is what produces the structural conditions for what Section 2.4.2 will analyze in biophysical detail as the *thermal wound* of the Lecce fringe.

Adell (1999, p. 39) refuses the spatial-only definition of the fringe entirely. He argues that the PUI is a multidimensional construct — spatial, economic, and institutional simultaneously, a tripartite characterization independently reached by Allen (2003, pp. 138–139), who organizes consecutive analytical sections around the ecological-spatial, socioeconomic, and institutional dimensions of fringe governance, giving the framework both empirical specificity and cross-regional transferability, and that any planning intervention that acts on only one of those dimensions will fail. The Salento confirms him to the letter. A typical Salentine household is multispatial in Adell’s sense: an early-morning olive harvest in a family grove, a midday job in Lecce’s service or tourism sector, an evening return to a residential parcel whose value is suspended in permanent limbo between residual agricultural yield and speculative residential potential. The economic logic of the territory is functionally virtual and de-localized, with land prices indexed less to current use than to anticipated re-zoning. The institutional logic falls between the jurisdictions of the urban Piano Regolatore Generale, the regional Piano Paesaggistico, and the rural-development programs funded under the Common Agricultural Policy. The spatial logic is the one cartography can map. The economic and institutional logics are the ones that determine whether what we map will still exist in five years.

The cartographic stakes are not academic. Mortoja and Yigitcanlar (2022) argue that correctly identifying fuzzy peri-urban growth boundaries is a precondition for protecting the agricultural and ecosystem services that constitute regional climate buffers. Their corollary is uncomfortable: rigid categorical boundaries — the official urban footprint, the cadastral parish line, the green-belt edge, capture only a fraction of the true peri-urbanization occurring at the fringe, leaving the rest invisible to planning instruments and therefore to protection regimes. In the Salento, this diagnostic invisibility is not a marginal problem. It is the problem. The methodological response to it, a higher-resolution analytical grid that converts the fringe into a continuum of measurable fine-grained units, is the subject of Section 2.1.6 and Chapter 3, and is not pre-empted here.

Defining the peri-urban buffer, then, is not a cartographic exercise. It is a reframing of what the territory is asked to do. The fringe of Lecce should not be read as a passive interface where the city ends and the countryside begins, but as an active, permeable membrane — a “porous, non-defensive infrastructure” whose climatic, ecological, and economic functions are continuous with those of the city it surrounds. The remainder of Section 2.1 builds on this position. Section 2.1.2 examines how speculative landscapes and the “urban shadow” fragment the membrane (Waldheim, 2016; Gallent & Shaw, 2007). Section 2.1.3 reads the residual ground of that fragmentation through Clément’s (2004) *Third Landscape*. Sections 2.1.4 and 2.1.5 reconstitute the membrane as a designable infrastructure, in dialogue with Banham (1971), Waldheim (2016), and the cultural-attachment literature. Section 2.1.6 then formalizes the gradient logic that Vizzari (2011) developed and that this thesis operationalizes through the 100-meter cell gridding methodology introduced in Chapter 3. The figure that closes the present section foreshadows the biophysical stakes of that operationalization.

Figure 2.7 Metabolic Inversion of the Rural–Urban Transition Zone, Lecce.



Note.

The author's schematic illustration transect through the fringe of Lecce, oriented from active olive matrix (right) to historic limestone core (left). The diagram makes legible the inversion that Section 2.4.2 will analyze in biophysical detail: where the territory should function as a vertical latent-flux engine (Zone 1, evapotranspiration cooling), the In-Place + Diffuse overlap has converted it into a horizontal sensible-flux conductor (Zones 3–5). The Tangenziale corridor operates as the thermal pivot. Surviving olive fragments inside the *Città Diffusa* appear as *captured rurality*, surrounded by sealed surfaces that override their cooling capacity. The historic core remains comparatively cool only by virtue of its high-albedo Pietra Leccese material, producing the reverse-UHI signature documented in Lecce by De Razza et al. (2024); empirical UHI anchors from Pappaccogli et al. (2024); SVF formulation after Pijpers-van Esch (2015).

2.1.2 The Urban Shadow and Speculative Landscapes: Mechanisms of Fragmentation

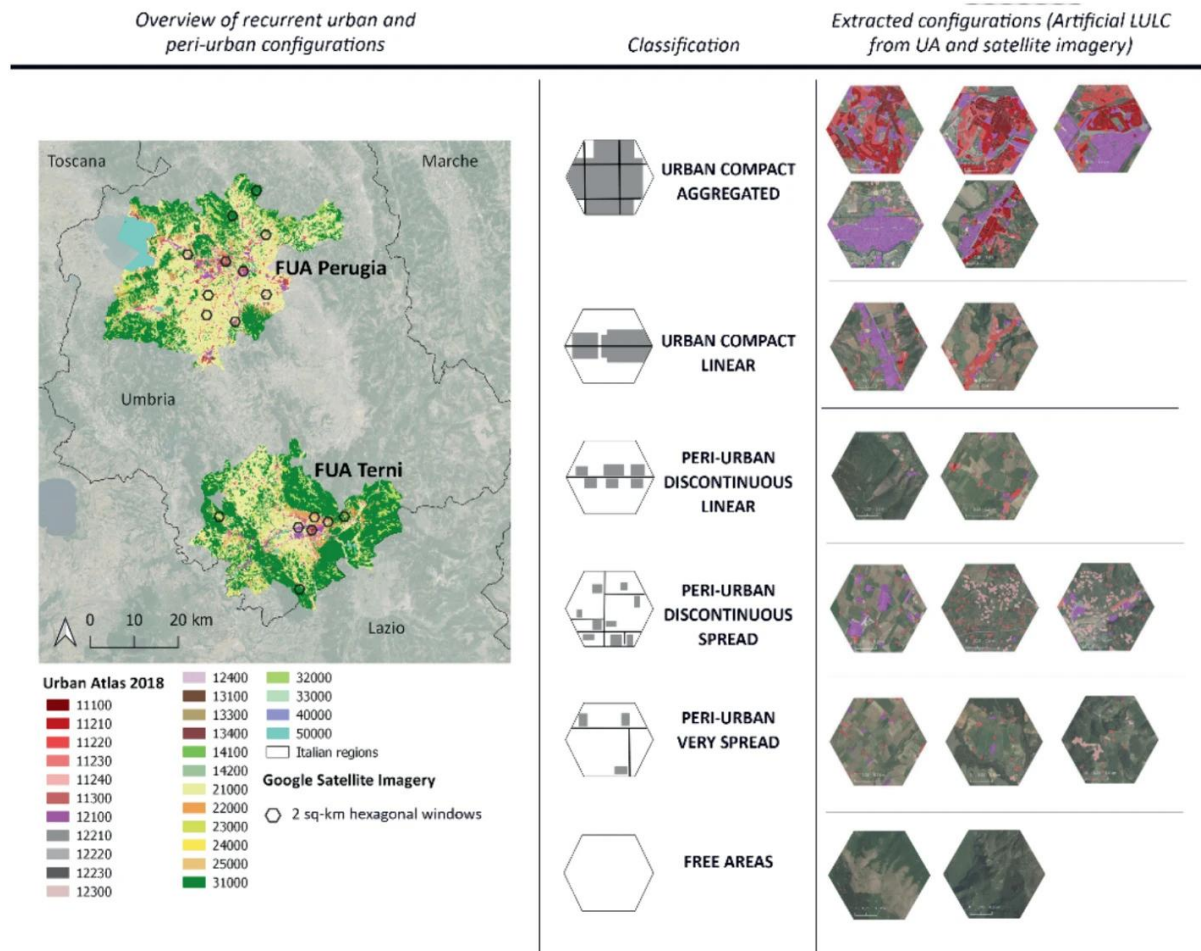
The thermal margin of Lecce's fringe is not simply the product of urbanization — it is the product of a prolonged, economically rational decision to hold land in a state of sustained biological death. This thesis terms this condition the “Urban Shadow”: not a geometric projection of the city's built form across the landscape, but a policy and economic vacuum where the light of regulatory oversight and the warmth of productive investment are obscured by the long-term anticipation of rezoning. Meeus & Gulinck (2008) identify the structural condition underlying this shadow: the semi-urban zone is a territory defined not by its current land use but by its uncertain futures, subject to anticipatory pressures that precede any formal urban conversion by years or decades. In this zone, farmers respond to the first stimuli of urban encroachment — land value inflation, the fragmentation of legacy irrigation networks, the impossibility of long-term capital investment in soil that may be sold within a decade — by initiating a tactical retreat from stewardship. Canopy renewal ceases. Drainage maintenance lapses. The muretti a secco crumble. The pruning cycles dissolve. The lame is filled with debris. The result is what Gallent & Andersson (2007) identify as the defining condition of the institutionally neglected fringe: a landscape that appears rural on the administrative map and is functionally dead in its metabolic performance. It is this landscape — not the fully urbanized core, not the intact olive grove — that the RUTZ Index is specifically designed to detect. (*For an applied reading of this framing in peri-urban Valencia and Copenhagen, see Padasas, 2019.*)

In Salento, this degradation is catastrophically accelerated by the *Xylella fastidiosa* epidemic, which has not merely killed trees but has dismantled the primary biological mechanism — canopy evapotranspiration — by which the fringe once managed solar radiation. The epidemic did not fall on a healthy landscape; it fell on a fringe already compromised by decades of stewardship retreat. The result is La Frangia in its most acute form: a burn zone not in the metaphorical sense of expanding suburbia, but in the thermal and ecological sense of a territory whose cooling capacity has been incinerated in advance of its formal urbanization. The RUTZ Index maps this inversion as La Frangia cells — characterized by high Impervious Surface Fraction (ISF), minimal Normalized Difference Vegetation Index (NDVI), and elevated Land Surface Temperature (LST) — the spatial signature of a landscape stripped of its metabolic function before a single planning permission has been granted.

The structural messiness of this shadow manifests in what Di Dato (2024) classifies as “Recurrent Urban Configurations” — typical spatial patterns where low-density housing, unauthorized industrial infill, and residual agricultural patches repeat in a state of morphological entropy across “fragile territories” where the loss of landscape legibility is a direct precursor to environmental risk. These patterns are visible in the municipalities of Cavallino, Lizzanello, and Surbo: the haphazard distribution of villas replacing contiguous olive groves, producing a porous but highly disordered fabric that lacks the thermal coherence of the historic core. The seventeen configurations Di Dato identifies are not

arbitrary categories — they are the spatial vocabulary of a specific form of territorial failure, legible precisely because it repeats: the same incomplete road endings, the same residual agricultural parcels besieged by sealed driveways, the same walled villa developments stranded between an intact masseria and a speculative void. In the Lecce fringe, these configurations are not exceptional events; they are the dominant fabric. (Figure 2.8)

Figure 2.8 Results of window classification within the Urban Atlas map and the 17 recurrent configurations.



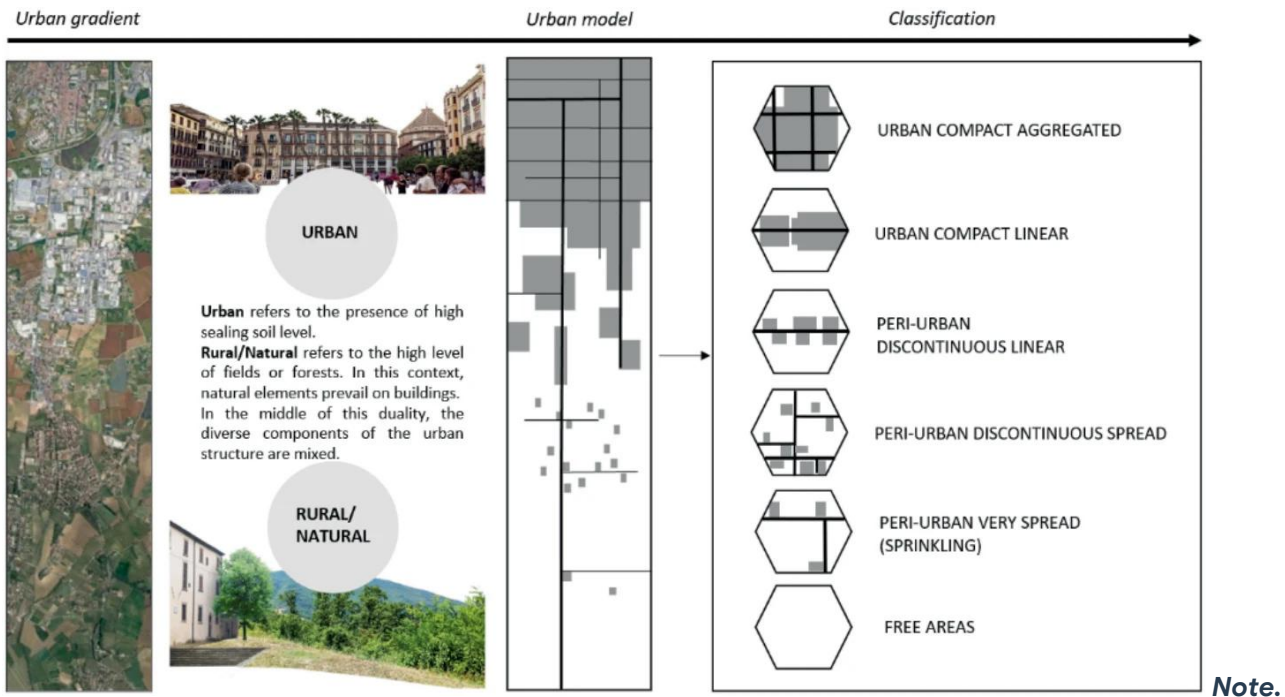
Di Dato, C. (2024). Methodological Approach for Classifying Typical Recurrent Urban and Peri-Urban Configurations. In O. Gervasi, B. Murgante, C. Garau, D. Taniar, A. M. A. C. Rocha, & M. N. Faginas Lago (Eds.), *Computational Science and Its Applications – ICCSA 2024 Workshops* (Vol. 14817, pp. 18–31). Springer Nature Switzerland.

Figure 2.8 makes this legibility visible: what reads as chaos at ground level resolves, at the classification scale Di Dato operates, into a finite set of recurring morphological conditions — each one a recognizable thermal typology, each one a spatial argument for why the RUTZ Index must classify at sub-neighbourhood resolution rather than relying on the homogenizing categories of standard land-use mapping. The disorder is not accidental. It reflects a structural process identified by Buxton (2006): the peri-urban fringe functions as a zone of impermanence in which land is held idle as an urban land bank, driven by speculative development and private land hoarding as landowners anticipate windfall profits from urban conversion. This process produces out-of-sequence and leapfrog

development while accelerating land value inflation and in doing so, it systematically prevents the long-cycle stewardship on which the fringe's ecological performance depends. Each enclosed former grove — concrete wall, dead stumps, compacted soil — becomes Augé's (1995) non-place: a space stripped of historical meaning and productive identity, existing only as a speculative figure on a balance sheet. It is also, precisely, the thermal hazard that the RUTZ Index registers: a shadow zone where the cessation of irrigation and canopy care has converted high-albedo Pietra Leccese and leaf-shade into dark, compacted, heat-absorbing surfaces, the exact inversion of what the fringe is required to provide.

The coexistence of incompatible land uses that defines this shadow is the structural condition Allen (2003) identifies as the essential characteristic of the peri-urban interface: a zone where farming operations, incomplete residential developments, unauthorized industrial infill, and speculative voids occupy the same territory in a state of competing interests and chronic conflict. Allen argues that this configuration is not merely a transitional disorder awaiting resolution, it is a specific support system in which the proximity of incompatible uses generates a vulnerability interface: the degradation of a single element directly stresses adjacent fabric, because each use depends on the spatial stability of those around it. In Salento, the thermal logic of this interface operates with particular severity. Unlike the peri-urban fringes of Northern European cities, where soil moisture, cloud cover, and higher humidity buffer the thermal consequences of land-use fragmentation, Salento's karst geology and Csa aridity provide no such redundancy. The loss of an olive grove does not merely reduce canopy in a landscape that has other evapotranspirative surfaces to compensate, it removes the only evapotranspirative surface available in a desiccated terrain. The strade provinciali radiating from the urban core — the SS101 toward Gallipoli, the SP83 toward Lizzanello, the SP4 toward Cavallino — act as the thermal wicks of this system, channeling capital and people outward while channeling heat deep into the rural matrix, blurring the thermodynamic boundary between the urban core and the agricultural sector far faster than any administrative map can register. What Allen identifies as conflictual coexistence is, at the cartographic scale, a gradient: not a binary edge between the urban and the rural, but a continuous spectrum of morphological conditions that passes through every possible degree of incompatibility before resolving, when it resolves into either consolidated urbanity or intact agricultural matrix. (*Figure 2.9*)

Figure 2.9 From the urban and rural extremes to a scheme of the urban gradient.



Di Dato, C. (2024). Methodological Approach for Classifying Typical Recurrent Urban and Peri-Urban Configurations. In O. Gervasi, B. Murgante, C. Garau, D. Taniar, A. M. A. C. Rocha, & M. N. Faginas Lago (Eds.), *Computational Science and Its Applications – ICCSA 2024 Workshops* (Vol. 14817, pp. 18–31). Springer Nature Switzerland. p. 24.

Figure 2.9 renders this gradient explicit: the spectrum from fully urban at one pole to fully rural at the other is not a theoretical abstraction but a spatial reality with measurable intermediate conditions. It is precisely those intermediate conditions — the cells that are neither city nor countryside — that the RUTZ Index is designed to read. The Lecce fringe does not sit at either pole of Di Dato's diagram; it inhabits its restless and thermally unstable center. The most devastating consequence of this economic logic is the systematic and silent abandonment of the Rural Techne of the Salento fringe. The meticulous maintenance of the muretti a secco, the traditional pruning rhythms of the olive groves, the manual clearing of the lame — these ancient, low-tech and local climate-management systems completely stop once land enters the urban shadow. The maintenance of the dry-stone walls is not an aesthetic choice: they historically acted as critical thermal and hydrological buffers, managing moisture in the thin karst soil and regulating surface temperatures through their thermal mass. When stewardship lapses, the walls crumble, the soil compacts, and the canopy is lost to neglect or disease. The landscape is physiologically primed for hazard long before a single concrete foundation is poured; by the time urbanization finally occurs, the cooling services of the former rural matrix have already been traded for short-term speculative gain, leaving the city without its primary thermal defense system. What the shadow makes invisible, the RUTZ Index makes it legible: at 100-meter resolution, it identifies exactly where the metabolic health of the landscape has been compromised by this cycle of speculative neglect, mapping the thermal scars of La Frangia that must be healed to restore regional resilience.

2.1.3 The Third Landscape: Residues and the “Urban Countryside” as Resilience Reservoirs

To shift from the diagnosis of fragmentation toward a prescriptive logic of recovery, the research requires a fundamental revaluation of the fringe — not as failed land awaiting urbanization, but as a territory whose very neglect has granted it a paradoxical productivity. This revaluation finds its philosophical anchor in Gilles Clément’s (2004) concept of the Third Landscape (*Le Tiers-Paysage*): the sum total of all spaces where the regulatory hand of human management has been withdrawn, allowing a primary biological evolution to reassert itself. Clément positions the Third Landscape as the residual category beyond both the shadow of power and the light of productive management — a space that expresses neither submission to economic optimization nor its denial. Within the Lecce thermal margin, this taxonomy of indecision manifests in three morphological forms that are simultaneously the most biologically rich and the most thermally productive spaces in the fringe: the *résidu*, the abandoned olive grove, the crumbling masseria; the *délaissé*, the accidental patch bypassed by a highway intersection or warehousing cluster; and the *réserve* the area of primary succession excluded from development not by policy but by neglect. The RUTZ Index does not treat these as planning voids to be resolved. It treats them as the most vital cells in the landscape network the primary reservoirs of the cooling capacity that La Frangia has destroyed.

The philosophical power of the Third Landscape rests on its recognition of “biological agency”: the capacity of abandoned or undecided territory to perform thermal and ecological work that the paved and air-conditioned city cannot sustain. In the Salento context, the parcels devastated by the *Xylella fastidiosa* epidemic represent what Clément would call a tragic but genuine “Planetary Garden” in formation. The cessation of intensive industrial monoculture — however economically traumatic — allows for the spontaneous emergence of resilient local species adapted to thin karst soils: halophytes, shrubs, pioneer grasses, and opportunistic macchia. While planners often view the post-*Xylella* landscape as a brownfield of skeletal wood and dry brush, through the lens of the Third Landscape, these areas are undergoing the Genetic Primary Movement of *Il Giardino* — the ecology of repair. The RUTZ Index captures this ambiguity precisely: declining NDVI (from > 0.50 pre-*Xylella* to < 0.15 in affected parcels by 2023) but persistent moisture signals in the lame, a territory losing one form of cooling while generating the biological conditions for another. Where urban planners see collapse, the gradient index reads a transitional state that must be protected rather than resolved by development.

Donadieu’s (2013) theory of the Urban Countryside (*Campagne Urbane*) translates Clément’s philosophical revaluation into a planning mandate: rather than the inevitable “urbanization of the countryside,” planners must master the art of “ruralizing the city.” The agricultural matrix is not a passive container for urban growth but a structural, permanent element of the metropolitan region, providing the green lungs and blue veins necessary for urban survival. In the Mediterranean basin, this requires the legal and conceptual

recognition that the “rurban” landscape; olive plantations, dry-stone wall networks, seasonal crops — provides collective ecosystem services (cooling, drainage, food security) that far transcend private property logic. The agroforestry studies of Dal Borgo et al. (2023) give Donadieu’s mandate its empirical mechanism: agroforestry systems act as drivers for multi-level assessment, improving agro-eco-mosaic structuring and increasing agricultural patch shape complexity, enhancing the territorial capacity to regulate microclimatic fluxes. In Lecce’s transition zone, this is not a future aspiration — it is the thermodynamic description of what the surviving olive matrix already does, and what the RUTZ Index maps as the Il Giardino and La Pietra boundary cells that must be protected from conversion into La Frangia.

To move from philosophy to operation, Aad et al. (2025) provide the assessment architecture for quantifying the revitalization potential of these marginal areas along four critical dimensions. Structural quality evaluates fragmentation versus continuity — the metastability of landscape components through metrics like Edge Density, revealing whether the matrix is still spatially coherent enough to sustain cooling flows. Ecological quality measures the richness of spontaneous biological sets and the ecological gap created by soil sealing through the Modified Shannon Diversity Index, capturing the biodiversity that Clément identifies as the Third Landscape’s primary value. Cultural quality catalogs the surviving Rural Techne — the pajare, torine, and muretti a secco as repositories of territorial memory with quantifiable thermal function, connecting Clément’s biological argument to the material intelligence of La Pietra. Visual quality identifies the functional conflicts between industrial infill and the rural matrix through the Disharmony Index, naming the specific spatial frictions that section 2.1.2 described as thermally lethal. Together, these four dimensions are the precise indicators the RUTZ Index integrates into its composite scoring, transforming Clément’s political concept of biological agency into a measurable, spatially specific claim about which cells of the Lecce fringe retain the capacity to function as cooling infrastructure. What the Third Landscape invests with philosophical value, the RUTZ Index maps, measures, and defends.

2.1.4 Landscape Urbanism and Territorial Infrastructure: The Operative Turn

The philosophy of the residue and the mandate to ruralize the city both require an operative logic capable of organizing the metropolitan region at the scale of its own metabolic complexity — and that logic is not architectural. It is territorial. This is the central claim of the Landscape Urbanism movement as articulated by Waldheim (2016): in the contemporary diffuse city, traditional architectural forms based on the arrangement of objects and buildings have failed to provide urban coherence in the face of rapid decentralization. Modernist planning’s archipelago of isolated structures separated by a chaotic, residual matrix is precisely the spatial condition the RUTZ Index is built to diagnose and measure. In this context, landscape emerges as the most capable medium for organizing the horizontal

metropolis — it provides the structural armature capable of bridging the gaps between built islands, ensuring that urban form emerges from ecological and territorial systems rather than from architectural objects alone. In Lecce, the Mediterranean Città Diffusa is already that archipelago; the RUTZ Index is the instrument that makes its ecological armature — or its catastrophic absence — visible at 100-meter resolution.

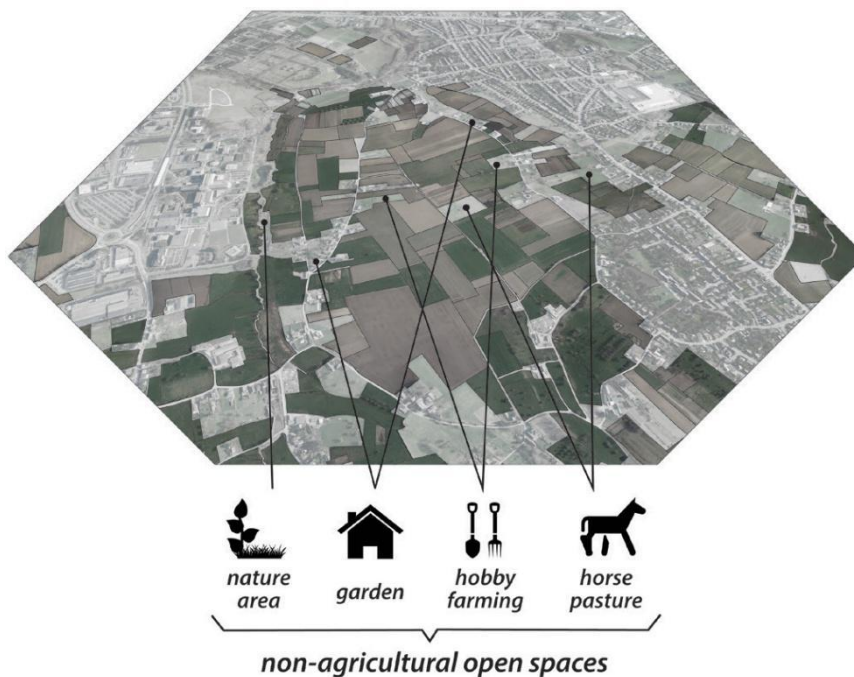
Central to this operative logic is Corner's (2003) concept of "Terra Fluxus," which identifies four ideas critical to the emergence of landscape as urbanism: process over time, horizontality, ecological infrastructure, and systemic performance. Of these, the most consequential for the RUTZ framework is the logic of process. Understanding any territory requires understanding the processes — hydrology, succession, and thermodynamics — that drive change over time, not merely the spatial forms those processes produce at a given moment. In Salento, Terra Fluxus is defined by the invisible movement of water through the karst aquifer, the slow decadal growth of macchia canopy on abandoned parcels, and the high-frequency thermal oscillations of the Mediterranean aridity cycle. By treating the territory as a continuous ecological surface — its Horizontality — the RUTZ Index does not map land use; it maps the metabolic flows of the hinterland, revealing where the cooling sea breezes and groundwater recharge are severed by the thermal walls of speculative sprawl. The map that results is not a spatial snapshot: it is a diagnostic of a process, and its clinical utility depends on the 100-meter resolution at which those processes operate.

This shift from object to system is given spatial grammar by Dee (2004) in *Form and Fabric in Landscape Architecture*. Dee proposes an original morphology based on the integrated relationship between fabric — the background matrix that gives a territory its identity — and form — the distinct figures within that matrix. Specific spatial elements such as hedges, dry-stone walls, paths, and groves function as morphological "units of resilience" that manage environmental performance through their geometry and materiality. The muretto a secco is thus analyzed not as an aesthetic relic but as a thermal battery: its porous limestone structure absorbs solar radiation during the day and releases it slowly at night, while its dry-stone joinery acts as a pervious armature for water infiltration into the karst soil. By cataloging these fabrics, the RUTZ Index establishes a direct link between the physical geometry of the wall and the metabolic health of the territory. Every La Pietra cell that registers anomalously low LST relative to its surroundings — approximately 31°C versus 42°C on adjacent sparsely vegetated soils — is, in part, the thermal signature of Dee's "fabric" doing exactly the work it was built to do.

The potential of this landscape-based approach to thrive in the marginal spaces of the Mediterranean fringe is argued by Sordi (2014) in *Beyond Urbanism*: the peripheral voids of the Mediterranean city should be reframed as productive landscapes of "dispersed resilience," acting as ecological design laboratories for climate adaptation. This decentralization is essential for Lecce, where climate hazards are concentrated precisely at the interface of the urban core and the fragmented fringe. The masterplan must be

replaced by a master-process: a design logic that facilitates the spontaneous recovery of ecosystems rather than imposing a predetermined spatial order on a territory already undergoing its own succession logic. De Waegemaeker et al. (2021) provide the methodological validation through Research by Design (RbD), demonstrating that visualizing landscape sections and thermal gradients is essential for making invisible climate phenomena — such as the Reverse UHI — legible to policymakers. Green open spaces in the fringe function as the city's primary climate buffers, and RbD allows the researcher to prove this at the spatial resolution that planning demands. The RUTZ Index is, in part, this proof: the map that translates the master-process into evidence. De Waegemaeker et al. (2021) give this logic its spatial grammar: a transect across the rural-urban fringe reveals not uniform degradation but a structured gradient of adaptive potential — zones where the landscape retains sufficient ecological continuity to buffer thermal stress, separated by zones where that continuity has been severed by fragmentation. The therapeutic landscape is not everywhere; it is findable, mappable, and designable. (Figure 2.10)

Figure 2.10 Landscape section diagram showing the climate adaptation gradient at the rural-urban fringe.



Note. From De Waegemaeker, J., Maarten, V. A., Kerselaers, E., & Rogge, E. (2021). The climate adaptation potential of the rural-urban fringe: Exploring the climate impacts in the Brussels' territory through research by design. *4D Journal of Landscape Architecture and Garden Art*, (60), 2–17. p. 3.

Figure 2.10 shows this gradient not as an abstract diagram but as a cross-

section of actual landscape conditions — each zone carrying a distinct combination of vegetation cover, soil permeability, and spatial openness that corresponds directly to a different thermal buffering capacity. In the Lecce fringe, the transition from the olive matrix's full adaptive potential to the sealed peri-urban surface's near-zero capacity occurs across a distance measurable in hundreds of meters — which is precisely why the RUTZ Index operates at the 100m cell, not at the municipal zone. These theories reach their most radical application in the post-Xylella fringe of Salento, where the territory is under simultaneous pressures — agricultural crisis, pathogen-driven canopy loss, speculative fragmentation, and climate intensification that no single masterplan can resolve in isolation.

As Corner (2003) argues through *Terra Fluxus*, the productive response to such complexity is not a predetermined spatial order imposed on the territory but an understanding of the processes driving its transformation: the timeline of ecological succession on abandoned parcels, the rate at which karst soil compacts under speculative vacancy, the seasonality of Adriatic breeze corridors through the fringe. The design strategy that follows is one of temporal occupation: rather than waiting for land to be formally rezoned before intervening, the practitioner works with the phases of biological succession already underway, pioneer species on compacted soils, *macchia* colonization of skeletal olive groves using these as the first stage of a multi-phase restoration process. This is the logic Sordi (2014) names the “master-process”: not a masterplan, but a master-logic of intervention calibrated to the territory’s own ecological tempo. The RUTZ Index is the bridge between this theoretical ambition and the spatial evidence it requires: at 100-meter resolution, it identifies precisely which cells are entering Il Giardino’s ecology of repair, which are locked in the La Frangia burn zone, and which retain the La Pietra thermal intelligence that the master-process must work with rather than pave over.

2.1.5 Sense of Place and Territorial Attachment: The Cultural Buffer

The thermal degradation of the fringe cannot be fully explained by land-use data alone. There is a prior failure — one that does not appear in any NDVI reading or albedo map — that drives the metabolic collapse the satellite later confirms. It is the erosion of territorial attachment: the severing of the community’s felt relationship to the landscape as a place of belonging, stewardship, and seasonal care. Albrecht et al. (2007) name this condition “solastalgia” — the distress caused by environmental change experienced within one’s home environment, a form of homesickness while at home, distinct from nostalgia precisely because physical separation is absent. In the Salento fringe, this is not a conceptual abstraction. The decimation of the olive groves by *Xylella fastidiosa* — currently the most economically and ecologically damaging plant disease in modern European agricultural history — is a trauma that transcends ecological loss. For generations, the silver-green canopy of the olive groves defined the horizon, provided thermal shade, and anchored the seasonal rhythms of Salentine life; its transition from a living planetary garden to a gray, skeletal residue is a visual wound that signals the psychological death of the territory — and, as the RUTZ Index confirms in declining NDVI and rising LST across the affected fringe, its thermal death as well. The satellite reads what the community has already felt.

This psychological wounding directly accelerates the expansion of the Urban Shadow. Where the landscape is no longer recognized as a “place” of belonging — where it has been converted into what Augé (1995) defines as a non-place, a space stripped of identity, relations, and history — its physical stewardship ceases. In the Salento fringe, the transition from anthropological place, the ancestral knowledge of soil and seasonal wind, the muretto repaired each winter, the olive row pruned in the correct lunar cycle to speculative void marks the collapse of the fringe’s soft resilience. Non-place is not merely a philosophical condition; it is a measurable thermal hazard. The fenced former grove in Surbo or the

abandoned masseria compound north of San Cesario di Lecce is the spatial expression of a community that has ceased to perform its climate function: no collective agency maintains the cooling canopy or the pervious stone walls, and the surface energy balance shifts toward unmitigated heat accumulation. The fenced void is not merely a speculative figure on a balance sheet, it is the precise spatial location where the Stone ecology dies and La Frangia or the ecology of Fire begins.

Magnaghi's (2015) concept of the Local Project (Il Progetto Locale) provides the theoretical framework for recovery. Writing from a bioterritorial perspective, Magnaghi argues that the territory is not a passive container for urban growth but a living organism resulting from the long-term co-evolution between human culture and the natural environment. Sustainable planning cannot succeed through top-down technical fixes alone; it must begin with the reactivation of "Coscienza di Luogo" — the collective ability of a community to recognize the territory not as a passive resource, but as a common good with its own laws of transformation and historical memory. In the Lecce fringe, the territory's metabolic buffer capacity is directly proportional to the community's willingness to engage in stewardship. The architectural elements of the fringe, the pajare and the muretti a secco — are the physical repositories of this territorial consciousness. If these are perceived as obsolete ruins rather than as functional climate infrastructure, they will continue to crumble, and their thermal functions will disappear with them.

If, however, these elements are reframed through the lens of a new rurality, their physical restoration is simultaneously a cultural and a thermal recovery. The muretto a secco is a breathable armature: it facilitates water infiltration into the karst aquifer, prevents soil erosion, and manages localized soil temperatures through thermal mass that no industrial material at equivalent cost can replicate. During the day, the porous limestone absorbs solar radiation while its high albedo reflects a portion of the incoming short-wave flux. At night, the wall releases stored heat slowly, preventing the sudden thermal shock to adjacent soil and vegetation that characterizes the bare surfaces of the Fire ecology. The family that maintains this wall performs climate maintenance in the most precise technical sense, this is what Magnaghi (2015) calls "territoriality": the inhabitant as producer of landscape quality rather than consumer of urban space. The RUTZ Index encodes this understanding by assigning measurable value to the integrity and legibility of traditional landscape fabrics. Psychological resilience, the feeling that the landscape is still alive and ours is not a supplementary social indicator appended to the spatial analysis as a footnote. It is a causal driver of the thermal performance the index measures: where territorial attachment is intact, the dry-stone walls are repaired, the canopy is pruned, the karst soil remains pervious, and again where it has collapsed, the Fire begins.

2.1.6 The Transition Zone as an Ecological Gradient: Mapping the Continuous

The theoretical layers assembled across sections 2.1.2–2.1.5, urban shadow, biological agency, territorial infrastructure, cultural attachment — each describe the fringe as a space

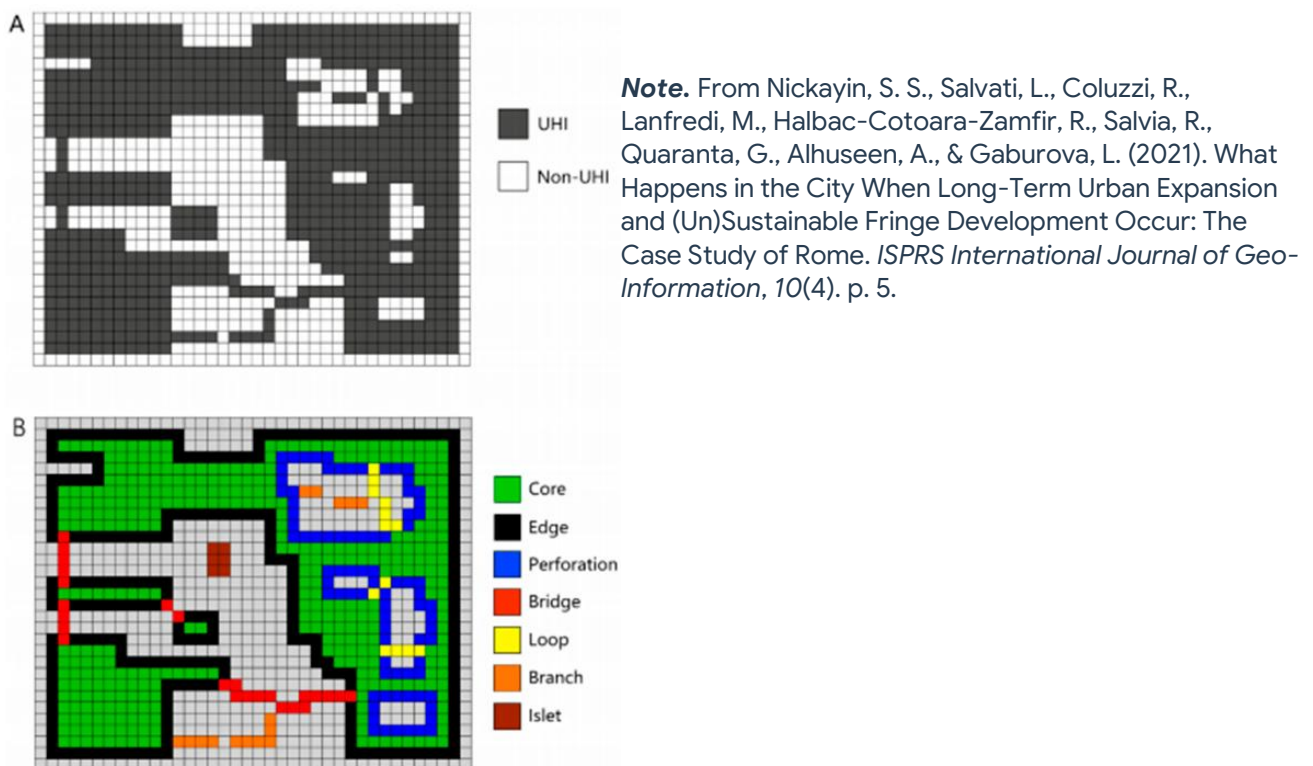
of complex, overlapping processes. But the planning instruments that currently govern it do not. They draw a line. On one side of the line, the territory is “urban”; on the other, it is “rural.” This binary cartography is not only epistemologically inadequate, it is thermodynamically dangerous, because it renders invisible the gradient dynamics that determine whether the fringe performs as a climate buffer or functions as a heat injector. The final theoretical move of the In-Between is therefore an epistemological one: the replacement of the boundary line with the concept of the Relational Field.

Vizzari (2011) gives this epistemological shift its spatial argument: urbanization must be understood as an ecological gradient producing gradual, non-linear modifications in ecological structures and functions across space, rather than abrupt shifts at a jurisdictional edge. In a binary model, a pixel is either urban or rural. In a gradient model, the same pixel is a site of exchange where proximity to the city influences biodiversity, water infiltration capacity, and surface temperatures through a spectrum of intensity that the binary cannot capture. Vizzari’s demand for indicators permitting the spatio-temporal quantification of this gradient is the theoretical mandate the RUTZ Index is designed to fulfill. The 100-meter fishnet grid is the instrument that makes the gradient legible: fine enough to capture the high-frequency spatial variability of the Salento landscape, the shadows of individual building clusters, the permeability of a single stone-walled field, the orientation of a primary street canyon, yet coarse enough to reveal the regional metabolic trends of the peninsula as a whole. This granularity is not a methodological preference; it is a scientific necessity. Nickayin et al. (2021) demonstrate that landscape connectivity loss occurs at a very fine morphological level, and in Salento, where land ownership is historically fragmented into small, irregular parcels, a coarser resolution would fail to capture the micro-fringe dynamics — the single olive grove, the stretch of dry-stone wall — that provide the only micro-cooling services in an increasingly scorched sprawl.

To move beyond land-use categories, Morphological Spatial Pattern Analysis (MSPA) has emerged in the scholarship as a method for classifying the landscape gradient into functional structural roles — Core, Islet, Edge, Bridge, Loop, and Perforation — each performing a distinct thermodynamic and ecological function within the green matrix. Nickayin et al. (2021) demonstrate that unmanaged fringe development systematically transforms stable Cores — the large, contiguous cooling engines of the countryside, into isolated Islets and Edges, significantly increasing the total perimeter of green space exposed to urban heat through structural fractalization. The Core provides maximum latent heat cooling and humidity regulation — in Lecce, this is the contiguous centennial olive grove or the karst garrigue that the RUTZ Index scores highest in the La Pietra cell range. The Islet is thermally besieged: small, disconnected, and desiccating rapidly as the Bowen ratio shifts toward sensible heat dominance in the absence of connection to larger cooling matrices. The Edge is the frontline of the Surface Urban Heat Island interaction — in thin Salento karst soils, heat penetration can desiccate an Edge cell up to 50 meters deep, killing its buffering potential before it reaches the interior.

The Bridge is the most critical and the most threatened asset in the Lecce fringe: the linear conduits — the lame, the agricultural wedges aligned with the Adriatic axis, the surviving rows of Aleppo pine along provincial roads — that allow sea breezes to bypass La Frangia hotspots and reach the urban center. The severance of a Bridge by speculative infill is a metabolic amputation: it prevents the cooling Adriatic breeze from flushing the urban canopy, creating the aerodynamic clogging that traps heat in the residential fabric. The Perforation is the most treacherous structural class: the single unshaded industrial pad or paved villa footprint inserted inside a green Core, creating a thermal hemorrhage that raises the interior temperature of the grove and triggers premature cessation of evapotranspiration. In Lecce's fringe, Perforation density is the spatial signature of anticipatory degradation made measurable — in thermodynamic terms, it is the rate of a Core's imminent collapse. The MSPA classification makes this structural vocabulary precise: each of the seven spatial forms it identifies — Core, Edge, Perforation, Bridge, Branch, Loop, Islet — performs a distinct thermodynamic function within the green matrix. To name the Bridge is to make the linear conduit of the lame legible as a planning object rather than a residual agricultural accident. (Figure 2.11)

Figure 2.11 Basic forms identified by the MSPA analysis: core, islet, bridge, loop, branch, edge, and perforation.



In Figure 2.11, the Bridge is the slender connector between larger green Core areas, topologically fragile, easily severed, and, once severed, irreplaceable by any planned substitute at comparable cost. In the Lecce fringe, every speculative villa development sited across a lame is a Bridge severance. The thermal consequence, the foreclosure of sea-breeze penetration into the urban core, and the creation of a heat-trap between two formerly connected green cores is not visible in the

development permit. It becomes visible only in the July LST map, three seasons later, when the damage is already done. In Salento, the Urban Shadow triggers a process of Structural Fractalization that is, in thermodynamic terms, a catastrophe. As Nickayin et al. (2021) demonstrate, this fragmentation creates a state of Topological Entropy, the breakdown of spatial order that leads to the total collapse of the Reverse UHI benefit. When the landscape reaches the Bifurcation Point of Resilience, the fragmentation threshold at which the unbuilt land in the fringe stops absorbing heat and begins injecting it, the regional energy balance flips. This threshold is invisible to any administrative map. It is only detectable through the gradient analysis that MSPA and the 100-meter fishnet make possible. By treating the transition zone as a continuous ecological gradient rather than a jurisdictional line, the RUTZ Index functions as a clinical monitoring instrument: just as a clinician tracks the vitals of a patient to detect internal malfunction before it manifests as crisis, the index monitors the vitals of the Lecce landscape — albedo, Sky View Factor, soil moisture index, Connectivity Probability — to detect, at sub-neighborhood resolution, exactly where the metabolic health of the fringe is beginning to fail. The acupuncture interventions the index prescribes, targeted reforestation, the repair of a specific muretto a secco in Cavallino, the de-sealing of a clogged pixel in the Lizzanello fringe, the restoration of a severed lama in Monteroni di Lecce are calibrated to the precise spatial location of the failure. The RUTZ Index thus shifts the practice of urban planning, at least in this territory, from the management of growth to the maintenance of metabolic health in the Mediterranean In-Between.

2.2 Mediterranean Urban Climatology: The Physical Argument

Before the data, the territory itself. The Lecce fringe carries its thermal condition as an atmospheric quality, legible to anyone who stands in it in the middle of July. The light flattens, the dust settles into the color of the limestone substrate, and the boundary between the city and what surrounds it dissolves into a single hot, exposed continuum in which the agricultural matrix has lost the canopy that once cooled it. This thesis has termed it as the *Thermal Margin* —the territorial reality the physical arguments of this section attempt to explain.

Figure 2.12 renders that reality as it appears to the body before it appears as data: an exposed continuum from the dense historic core, through the discontinuous urban fabric, to the agricultural and peri-urban terrain at the right edge, where the surface burns and the soil moisture is gone.

Figure 2.12



Note. The Thermal Margin — atmospheric study of the Lecce urban–rural transect, Province of Lecce, Italy. The dense historic limestone core (left) gives way to discontinuous urban fabric (center) and to the agricultural and peri-urban terrain at the conflictual fringe (right), where extreme surface temperatures and depleted soil moisture mark the failure of the climate buffer function. Original illustration by the author, developed in collaboration with Prof. Antonio Di Campli for the Thermal Margin working paper, 2026.

What the atmosphere makes felt, the climatology makes physical.

2.2.1 The Mediterranean Climate as Thermal Amplifier

Summer in Salento is not a season of warmth. It is a siege. From the first days of June through the last weeks of September, the sky over the Lecce basin closes into an unbroken dome of solar radiation, rainfall disappears, the aquifer retreats, and the air desiccates as it heats, stripping the landscape of the very moisture that vegetation relies on to cool itself. This is not a regional peculiarity or an anomaly to be explained away. It is the structural condition of the Csa climate regime: the hot, dry-summer Mediterranean type in the Köppen-Geiger classification, defined precisely by the seasonal decoupling of heat and moisture. Rain falls in winter, when the Azores High retreats north. When it returns in June, it blocks Atlantic moisture from reaching the peninsula for three consecutive months, and in its absence the Salento fringe reaches a condition that no northern European planning framework was designed to address.

The basin this climate belongs to is accelerating beyond its own historical baseline. Lionello and Scarascia (2018), synthesizing twenty-eight CMIP5 global climate model simulations across the combined historical and projected period 1901–2100, establish the precise quantitative relationship: annually, the Mediterranean region warms approximately 20% faster than the global mean surface temperature; in summer, that amplification rises to approximately 50% above the global rate. The divergence is statistically significant as a 21st-

century signal, distinguishing a 20th-century period when regional and global temperatures tracked relatively closely from a trajectory of accelerating separation. The IPCC Sixth Assessment Report's Cross-Chapter Paper on the Mediterranean Region, frame the consequence at the basin scale: the Mediterranean is a confirmed climate-change hotspot, and its exposure is not uniform but concentrated in the semi-arid south — in Puglia, in Salento, in the precise territory this thesis examines. Giorgi (2006), writing the foundational hotspot characterization that subsequent IPCC reports have validated and extended, identified the Mediterranean as one of the two primary climate-change hotspots globally, coupling pronounced warming with a structurally drying precipitation regime.

What this acceleration means for the Lecce fringe is not a matter of average temperatures rising gradually toward some future threshold. It is a present-tense territorial condition. The Csa summer delivers nine consecutive hours of solar radiation onto surfaces with no moisture to spend, the karst soil's spring moisture charge has long since evaporated, the olive groves that once transpired it back into the boundary layer are increasingly dead or dying, and the sealed surfaces of the expanding fringe absorb incoming radiation without any biological mechanism to redirect it. A Northern European planner working with a thermal buffer framework calibrated to the wet, cloud-buffered summers of Hamburg or Rotterdam cannot transplant that instrument to a territory where the atmospheric boundary conditions are structurally different. In Salento, the fringe is not a mild transition between urban and rural thermal regimes. It is the territory where two extreme systems — the city's accumulated thermal mass and a rural landscape that has lost most of its cooling infrastructure, press against each other with nothing between them.

The spatial consequence is the one that §1.1 introduced with a single number: on the 24th of July 2022, bare and sparsely vegetated peri-urban soils reached 42.25 °C against 31.44 °C on the Pietra Leccese limestone of the historic core and 40.32 °C on the city's impervious surfaces (De Razza et al., 2024). The fringe was the hottest terrain in the province. That thermal inversion does not resolve under the Csa climate it deepens with, because the amplification that Lionello and Scarascia (2018) document falls most heavily on precisely the territory that has lost the vegetative cooling mechanism that once mediated it. The Lecce fringe sits at the boundary between the city's thermal management system and a rural landscape in progressive collapse. The climate makes this boundary active rather than passive. It is where thermal stress is produced, accumulated, and if the buffer function is defended, where it can also be interrupted.

2.2.2 The Reverse UHI and What It Tells Us About the Fringe

The canonical urban heat island places the city at the center of the thermal anomaly and the countryside at its relieving periphery: the city burns, the rural margins cool it. In Lecce, this relationship is inverted. The historic limestone core is cooler than its surrounding fringe, not warmer. Understanding why that inversion occurs is the entry point into what the fringe has

lost and what a classification instrument for Mediterranean transition zones must be designed to capture.

The physics are foundational. Oke (1987), in the definitive account of boundary layer climatology, establishes the surface energy balance as the framework through which any landscape's thermal behavior must be read: incoming solar radiation is distributed across sensible heat transfer (which warms the air), latent heat exchange (the evaporative cooling of moisture into vapor), heat storage in the substrate, and horizontal advection. What determines whether a surface heats or cools the air above it is the ratio in which it partitions incoming energy across these pathways. The city's dense fabric stores heat in its thermal mass and re-emits it slowly but the historic core of Lecce adds a dimension most urban climate models do not account for: its Pietra Leccese facades reflect a substantial fraction of incoming solar radiation before any partitioning can occur. The fringe, by contrast, has lost its latent heat pathway, the evapotranspiration of olive canopy that once consumed the majority of incoming solar energy and replaced it with bare karst soil and sealed asphalt that redirect nearly all radiation directly into sensible heat. More incoming energy, no biological cooling, no reflective stone: the fringe becomes the thermal worst case.

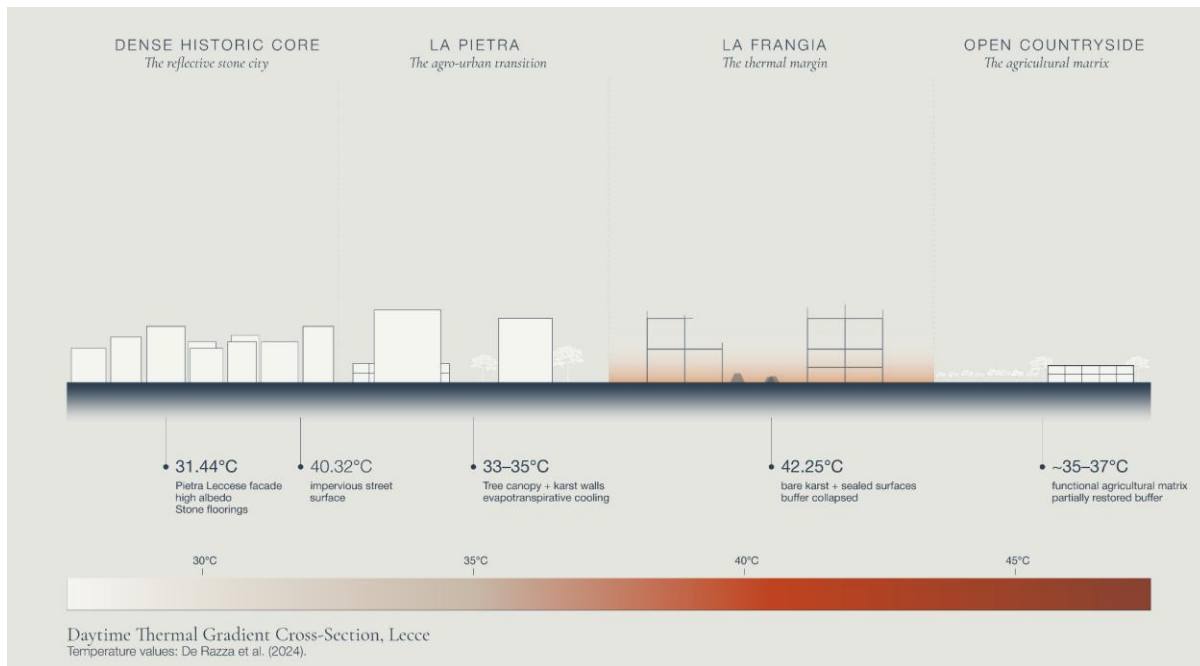
Donateo et al. (2023), monitoring near-surface temperature at five stations across Lecce's urban-rural gradient over nine years from 2013 to 2021, document the temporal signature of this condition with precision. The urban heat island intensity peaks at night, ranging from 1.1 to 1.6 °C in the city's core relative to suburban stations, a nocturnal signal consistent with the city's thermal mass slowly discharging the day's stored energy into the cooling air. During the day, particularly during heatwaves, the pattern reverses: suburban and fringe stations record the highest temperatures, while the dense urban core benefits from the combined effect of mutual shading between buildings and the albedo of its limestone surfaces. The nine-year analysis also registers a significant deterioration of thermal comfort across the monitoring period, not a plateau, but a worsening trajectory that tracks the simultaneous progression of fringe sprawl and Xylella-driven canopy collapse. Pappaccogli et al. (2024), tracking six weather stations across the city over four years (2020–2023), find that the greatest urban heat island intensity during heatwave periods 2.60 °C is recorded at the densely urban ARPA station, while stations surrounded by green areas or located in suburban settings consistently show the lowest values. The fringe is performing the opposite of its theoretical function.

Pappaccogli et al. (2025), applying high-resolution ECOSTRESS thermal data against both GIS-derived and WUDAPT-derived LCZ classifications in Lecce and Milan, confirm that the Local Climate Zone (LCZ) framework captures a portion of this thermal heterogeneity — but with systematic distortion at precisely the fringe typologies that matter most. For Lecce's historic districts LCZ 2 (compact midrise), the data corroborate the daytime cool-island effect, with lower LST explained by the light-colored, high-thermal-capacity Pietra Leccese construction material. For peri-urban and sparsely built zones LCZ 6 (open low-rise), and LCZ 9 (sparsely built), the classification methodology significantly influences the thermal

results: WUDAPT overestimates LCZ 6 and LCZ 8 (large low-rise) while underrepresenting more compact types, and the resulting LST distributions differ significantly from GIS-based classifications. The fringe is thermally heterogeneous at a scale that composite-pixel LCZ assignment systematically conceals.

The reverse UHI, read in this light, is not an anomaly that Lecce should take comfort in. It is the thermal signature of a fringe that has lost its ecological function. The city is cooler during the day because it has the density to generate mutual shading and the Pietra Leccese to moderate its albedo. The fringe is hotter because it has neither the density of the city nor the canopy of the agricultural matrix it used to be. It is, in the language this thesis uses, a thermal orphan — expelled from both the strategies that could have regulated it. The reverse UHI is not the problem. It is the diagnostic instrument that reveals the problem: a fringe whose buffer function has collapsed, leaving the city exposed at night when the stored heat radiates outward, and leaving the fringe's own inhabitants in the thermal worst case during the day. Figure 2.13 illustrates this argument spatially: a thermal cross-section from the historic limestone core through La Pietra and into La Frangia that does not describe zones but measures a gradient — an 11 °C surface temperature difference produced not by distance but by material choices, ecological collapse, and the absence of a buffer that once stood between them.

Figure 2.13

**Note.**

Daytime thermal gradient cross-section across the Lecce urban-rural transect. From the dense historic core (Pietra Leccese facades, ~31 °C; impervious street surfaces, ~40 °C), through La Pietra (olive canopy and karst walls, ~33–35 °C), into La Frangia (bare karst and sealed surfaces, ~42 °C), and onward to the open countryside (functional agricultural matrix, ~35–37 °C). Surface temperature values are peak summer Land Surface Temperature (LST) measurements; the 11 °C inversion between limestone core and bare-soil fringe is the central quantitative claim of section 2.2. Original illustration by the author. Temperature data: De Razza et al. (2024).

The 11 °C measured across this cross-section is not, in the end, a difference in climate. It is a difference in territorial intelligence, the cumulative consequence of material choices, ecological maintenance, and morphological calibration that the chapter must now examine systematically, register by register, beginning with the question of urban form itself.

2.2.3 Albedo, Materiality, and the Pietra Leccese Anomaly

In the Csa climate, where every other thermal management mechanism is under pressure, evapotranspiration fails when moisture is absent, ventilation fails when high-pressure domes suppress wind, vegetation fails when pathogens remove the canopy, albedo is the one passive property that does not depend on water, wind, or biology. A surface either reflects incoming solar radiation before it can become heat, or it does not. The Pietra Leccese, the pale calcarenite of the Lecce basin has a reflective advantage that comes from geology: a Miocene limestone formed from compressed marine organisms, cream-colored, porous, with a surface reflectance significantly above the industrial materials of the fringe.

De Razza et al. (2024) establish the spatial evidence for what this material difference produces in practice. Their Landsat-8 albedo analysis of the July 2022 heatwave event in Salento confirms that the characteristics of building material in the historical sectors of the city play a decisive role in the reverse UHI effect: the historic limestone surfaces reflect a substantially higher fraction of incoming shortwave radiation than the dark bitumen and

concrete of peri-urban sprawl. Where the Pietra Leccese is present — in the historic center, in the intact masserie of the agricultural fringe, it modulates the surface temperature regime. Where it is absent, in the villa developments of La Frangia, in the industrial sheds of Surbo and Lizzanello, on the sealed driveways and access roads that seal former agricultural parcels that modulation disappears. What De Razza et al. (2024) and Donateo et al. (2023) together confirm is that the albedo differential between an intact Pietra Leccese surface and a sealed asphalt parking lot is not a minor increment: it is the physical substrate of the thermal gap between 31 °C and 42 °C that the satellite registered on July 24, 2022.

This is not an aesthetic observation. It is a quantifiable thermal differential that the RUTZ Index's albedo indicator layer is designed to capture at 100m cell resolution. The RUTZ Index's central argument that Stone, Fire, and Shadow are thermally distinct ecologies with measurably different buffer capacities rests in part on the albedo signal that separates them. Where the Pietra Leccese surface persists in the fringe, in the historic masseria compound and the karst wall network, the albedo signal is anomalously high relative to surrounding development. Where it has been replaced by globalized construction materials, the signal collapses. The RUTZ Index does not merely map this, it treats it as primary morphological evidence of the thermal consequence of every material choice made at the fringe.

2.2.4 Wind, Ventilation, and the Porosity Question

Lecce sits thirteen kilometers from the Adriatic coast and twenty-five from the Ionian, and its summer climate bears the partial mark of both. The diurnal sea-breeze regime — driven by the temperature differential between the heated Salento landmass and the cooler surrounding seas delivers a westerly to south-westerly airflow during the late afternoon and early evening that provides partial nocturnal cooling relief. Donateo et al. (2023) confirm that urban heat island intensity decreases significantly when north winds exceed 3 m/s, and that stagnant conditions, calm winds under the high-pressure domes that characterize Mediterranean heat events, produce the most severe thermal accumulation. Martinelli et al. (2020), studying Mediterranean coastal urban heat islands including Bari, establish the broader regional pattern: sea breeze ventilation is a critical modulator of summer urban overheating in peninsular southern Italy, and its effectiveness depends entirely on whether the peri-urban fabric allows it to penetrate.

The fringe's role as either conduit or barrier to this ventilation depends on its spatial configuration. An intact agricultural landscape, olive groves with loose canopy structure, field boundaries of dry-stone walls that channel rather than block airflow, wide open parcels aligned with prevailing breeze directions, presents low aerodynamic resistance to incoming cooler air. A sealed, walled villa development, a continuous industrial shed frontage, a fragmented mosaic of enclosed parcels without inter-visibility — these structures increase surface roughness dramatically, forcing the sea breeze to dissipate its energy in turbulence before it can reach the city. The porosity of the fringe is therefore not only an ecological

parameter but a ventilation parameter: it determines whether the Adriatic and Ionian breezes reach the historic core or are spent at the periphery. This principle, that landscape fragmentation has ventilation consequences, is the reason the RUTZ Index's fragmentation metrics enter the composite index not only as ecological measures but as indicators of ventilative capacity. The specific fragmentation metrics that operationalize this principle — number of patches, edge density, Euclidean nearest-neighbor distance — are introduced and decoded in section 2.5.

2.2.5 The Air Conditioning Feedback and the Metabolism of Sprawl

Low-density fringe sprawl generates a demand for mechanical cooling that releases heat into exactly the outdoor environment that residents are trying to escape. Every split-system air conditioning unit running in a La Frangia villa expels its waste heat — the thermal load it has extracted from the interior — into the already-overheated air immediately around the building. In aggregate, across a fringe characterized by isolated villas with high window-to-wall ratios and negligible canopy shade, this waste heat rejection constitutes a diffuse but persistent anthropogenic heat source distributed across precisely the territory where the city's thermal buffer should be functioning. Pappaccogli et al. (2024) document that the cool-island effect in Lecce is most vulnerable when wind speeds drop below 3 m/s — the precise stagnant conditions under which air conditioning demand peaks and waste heat cannot be flushed from the outdoor environment. The feedback is mechanical: more heat demands more cooling, more cooling produces more waste heat, more waste heat raises the outdoor temperature that the next cooling cycle must overcome. The fringe generates the problem it is trying to escape from. What distinguishes this from a merely technical observation is its spatial character: the feedback concentrates in the fringe precisely because the fringe lacks the canopy that would intercept the waste heat before it recirculates into the boundary layer. Defending the fringe's ecological function is, among other things, the precondition for breaking this loop.

2.3 Morphological Indicators: Reading the Fringe as Structured Space

If section 2.2 establishes why the Lecce fringe burns, this section asks how its morphology either resists or amplifies that burn. Urban form is not a neutral container for climate — it is the instrument through which solar radiation is either absorbed, reflected, evapotranspired, or stored. The four subsections that follow trace that instrumentality across four scales: section 2.3.1 introduces the canonical morphological parameters that classical urban climatology relies on; section 2.3.2 examines what those parameters measure and where they fail; section 2.3.3 reads the vernacular architecture of the Salento fringe as a calibrated thermal infrastructure that pre-dates urban climatology and outperforms it; and section 2.3.4 confronts the Local Climate Zone framework with the heterogeneous Mediterranean morphologies it was not designed for.

2.3.1 From Urban Morphology to Thermal Performance: The Spacematrix Lineage

Urban morphology has spent decades developing rigorous instruments for reading built density as a spatial variable. The tradition that most directly bears on the RUTZ Index's methodological choices runs through the Spacematrix, the spatial density framework developed by Pont & Haupt (2023) out of Delft, which assembles the Floor Space Index, Ground Space Index, Open Space Ratio, and building height into a relational system capable of comparing urban fabrics across cities, scales, and typologies. What Spacematrix accomplished was to shift the analytical unit from the building to the fabric: the relevant morphological question is not how tall a structure is but how its footprint, its open space, and its height interact to produce a specific spatial configuration, one that has consequences for solar access, wind penetration, surface temperature, and the experience of the street.

The RUTZ Index inherits two specific indicators from this lineage: Building Surface Fraction (BSF) and Impervious Surface Fraction (ISF). BSF, the proportion of a cell's surface covered by building footprints, measures the built density of each 100m grid cell; ISF, the proportion covered by impervious surfaces including roads, parking, and sealed agricultural land, measures the combined thermal burden of all sealed surfaces within it. Both are adapted from the Spacematrix tradition's sensitivity to the relationship between built form and open space, and both were initially calibrated at the neighborhood scale of the consolidated city. This calibration matters. Spacematrix was designed for the Dutch urban condition: relatively dense, morphologically regular, the FSI and GSI varying within a range that city planners could use to compare alternatives for a city block or a district. The peri-urban fringe of Lecce does not operate within that range, nor at that scale. Its heterogeneity occurs at the sub-100m level: a single fishnet cell in La Frangia may contain a sealed driveway, a dead olive grove, an incomplete villa foundation, and a surviving fragment of dry-stone wall, four thermally distinct surface types averaging into a single BSF and ISF value that conceals precisely the variation that matters. Applying these indicators to the fringe is not a deficiency of the methodology. It is a deliberate methodological adaptation whose theoretical justification is the central contribution of Chapter 4. The RUTZ Index inherits the indicators and extends their application to a territory and a resolution they were not designed for, because no instrument that confines itself to either the neighborhood scale or the ecological scale can hold what the fringe requires.

One methodological precedent must be named and then set aside. Morphological Spatial Pattern Analysis (MSPA), the approach applied by Nickayin et al. (2021) and Vizzari (2011) to categorize the landscape into functional structural classes, represents an important thread in the fragmentation literature from which the RUTZ Index draws. Its classification of Core, Edge, Bridge, Islet, and Loop structures captures dimensions of landscape connectivity that relate directly to the thermal and ecological arguments of this thesis. It is not, however, part of the RUTZ Index's operational methodology. The RUTZ Index employs a direct fragmentation metrics stack number of patches, edge density, nearest-neighbor distance,

largest patch index, applied at the 100m fishnet scale rather than running MSPA across the continuous landscape raster. The choice reflects a resolution and integration logic that §2.5 documents in detail. MSPA is the precedent; the RUTZ metrics are the adapted instrument.

2.3.2 Fragmentation as Thermal Evidence: The Landscape Metrics Stack

The olive grove does not cool in isolation. It cools as part of a continuous canopy system — a network of moisture exchange, shade overlap, and evapotranspirative output that depends on its spatial coherence. When that coherence is broken — when the grove is fragmented into patches by sealed roads, villa driveways, and abandoned parcels — the thermal function does not diminish proportionally. It collapses above a threshold. Each patch that remains is increasingly surrounded by a thermally hostile surface: the exposed edge of the patch absorbs heat from adjacent bare soil, the patch's interior becomes smaller relative to its perimeter, and the moisture that the canopy depends on drains more rapidly from the disconnected soil. A landscape of many small, isolated patches is more thermally exposed than a landscape of large, continuous patches not because the total vegetation area is smaller, but because fragmentation destroys the microclimatic continuity that allows canopy to moderate surface temperature.

Meeus and Gulinck (2008), reviewing the literature on semi-urban areas in landscape research, establish the conceptual framework that gives fragmentation metrics their analytical weight in peri-urban contexts: the semi-urban gradient is not a smooth continuum between consolidated urban and deep rural conditions but a landscape of abrupt transitions, orphaned patches, and structural discontinuities produced by the collision of incompatible land uses. Their framework positions fragmentation not as a secondary ecological phenomenon but as the primary spatial signature of the peri-urban condition, the measurable mark of the processes of land conversion that section 2.1 examined at the institutional and metabolic scale. Vizzari (2011), applying spatio-temporal analysis to the urban-rural gradient of an Italian peri-urban fringe using landscape metrics, demonstrates that the gradient's ecological and thermal performance is legible through exactly the kind of patch-based metrics that the RUTZ Index assembles. Nickayin et al. (2021), tracing the consequences of long-term fringe development in Italian municipalities, confirm that unmanaged peri-urban expansion systematically transforms large, thermally stable landscape cores into fragmented networks of isolated patches, with measurable consequences for the ecological and thermal services those patches once provided.

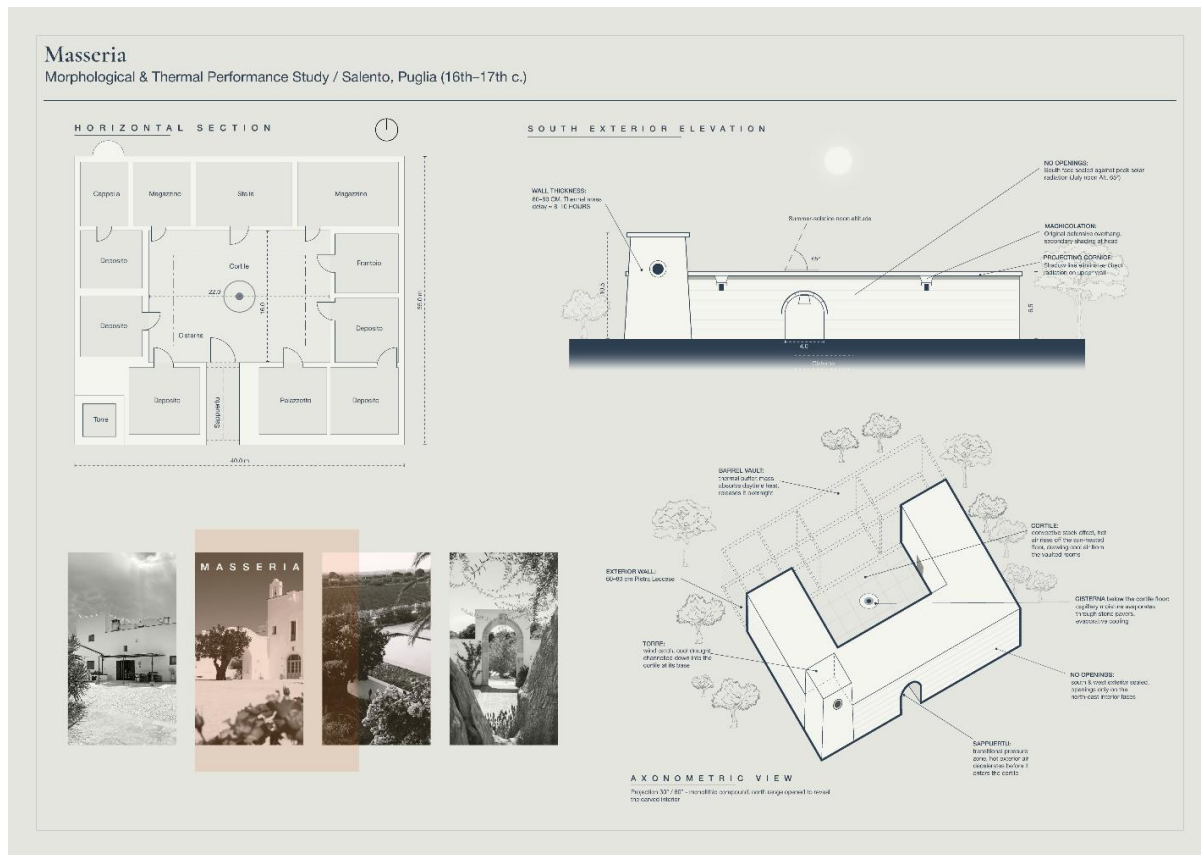
The RUTZ Index's fragmentation stack assembles four metrics, each measuring a different dimension of the fringe's structural resilience. Number of Patches (NP) counts the breaks: a high NP in an olive-grove cell signals that the canopy has been fragmented into many small pieces, regardless of the total area they cover. Euclidean Nearest-Neighbor Distance (ENN) measures the isolation between surviving patches: a high ENN means that the fragments

are spatially separated to the point where the biological corridor function — moisture exchange, seed dispersal, thermal continuity — is broken between them. Edge Density measures the ratio of thermally exposed boundary to protected interior: a high edge density signals a landscape in which almost every point of vegetation is within radiative distance of a hot bare surface, preventing the development of a stable internal microclimate. Largest Patch Index (LPI) measures whether any dominant patch retains enough area to function climatically: an LPI above a meaningful threshold signals a cell where at least one patch is large enough to generate its own microclimate; an LPI near zero signals a cell where every surviving piece of vegetation is too small to do so. Together, these four metrics are not a statistical toolkit. They are a reading of the landscape's structural resilience, its capacity to continue buffering heat under the compounding pressures of sprawl, abandonment, and pathogen-driven canopy collapse. Applied to the Lecce fringe at 100m resolution, they allow the RUTZ Index to distinguish between a cell that retains ecological coherence and a cell that has already crossed into the incoherence of La Frangia.

2.3.3 The Vernacular as Thermal Infrastructure: Masserie, Muretti a Secco, Trulli, and Pajare

The masseria compound of the Salento fringe is not an architectural type. It is a climate management system that took centuries to calibrate to the specific thermal conditions of this limestone peninsula. Thick walls of Pietra Leccese, calcarenite with albedo values that the RUTZ Index registers as a distinct anomaly against surrounding bare soil, absorb daytime heat slowly and release it gradually overnight, damping the diurnal temperature swing that exposes unprotected surfaces to extreme peaks and troughs. The internal cortile functions as a passive ventilation stack: as the stone walls warm through the afternoon, convective air currents rise from the central open space, drawing cooler air through the lower arcades from the shaded perimeter. Below grade, the underground cisterna, the stone tank that collected winter rainwater for summer use, maintains a moisture gradient in the soil column that the surrounding agricultural parcels can draw on during the driest months, sustaining a residual evaporative cooling function that bare-soil cells long since forfeited. The projecting cornice that crowns the masseria's exterior wall face casts shadow across the base of the wall at the solar angles relevant to the July peak, not because the builders calculated solar geometry, but because centuries of adaptation had already solved it. When the RUTZ Index identifies a cell with anomalously low LST and anomalously high albedo in what should be the thermal worst-case zone of La Frangia, it is often reading the thermal signature of an intact masseria compound. The detection of that signature is not incidental, it is the index's confirmation that the Stone ecology persists as a functioning thermal ecology even within cells that would otherwise classify as La Frangia. Figure 2.14 makes that thermal logic legible at the architectural scale, not as heritage documentation, but as a technical argument: every spatial decision visible in the compound section, from the projecting cornice to the subterranean cisterna, is a calibrated response to the same solar and moisture conditions that the RUTZ Index attempts to quantify from space.

Figure 2.14

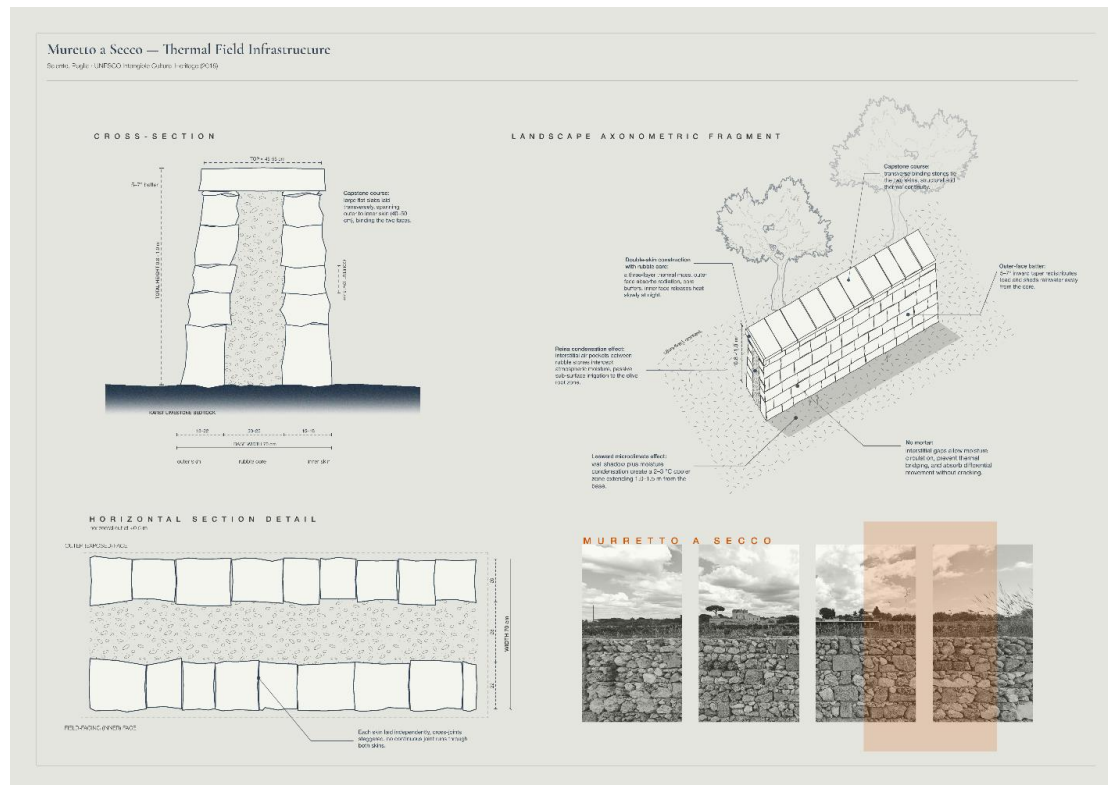
**Note.**

Masseria compound as passive climate management system, Salento. Original illustration by the author.

What the masseria concentrates within its compound walls, the dry-stone wall network extends across the field matrix at the territorial scale. The muretti a secco, the dry-stone walls that grid the Salento landscape into an agricultural mosaic, are not field boundaries. They are thermal and ecological infrastructure performing functions simultaneously that a sealed boundary cannot. Their windbreak function reduces convective heat transfer across exposed soil: a wall of double karst limestone construction with loose infill, the traditional Salento muratura a secco construction that Franin et al. (2019), studying Mediterranean dry-stone walls in comparable Adriatic olive grove contexts, confirm hosts the highest biodiversity of arthropods relative to wall-distant field interiors, acts as a porous barrier that reduces the horizontal movement of hot air without entirely blocking it. Their moisture retention function is more subtle: the loose-packed karst infill slows the evaporation of soil moisture from the ground immediately adjacent to the wall, maintaining a residual humidity gradient that sustains the moisture-starved vegetation on the field's leeward side through the driest periods. Their shadow projection at solar noon in July, calculated from the wall height and solar altitude, shades the soil immediately at the wall base during the hours of maximum radiation load. Their fragmentation pattern in the ENN and Edge Density metrics directly reflects their physical discontinuity in the landscape: when dry-stone wall networks are mapped through landscape fragmentation analysis, a severed network produces exactly the elevated ENN and edge density values that the RUTZ Index reads as thermal

incoherence. The wall and its metrics are continuous. A severed dry-stone wall network is a severed thermal network. Figure 2.15 cross-sections the muretto at the moment of maximum performance, the microclimate banding it produces in the soil column immediately adjacent to its base, the moisture gradient it maintains in the capillary zone, the shadow it casts across the bare karst at solar noon, functions that the RUTZ Index reads simultaneously through its combined ENN, edge density, and LST anomaly metrics.

Figure 2.15

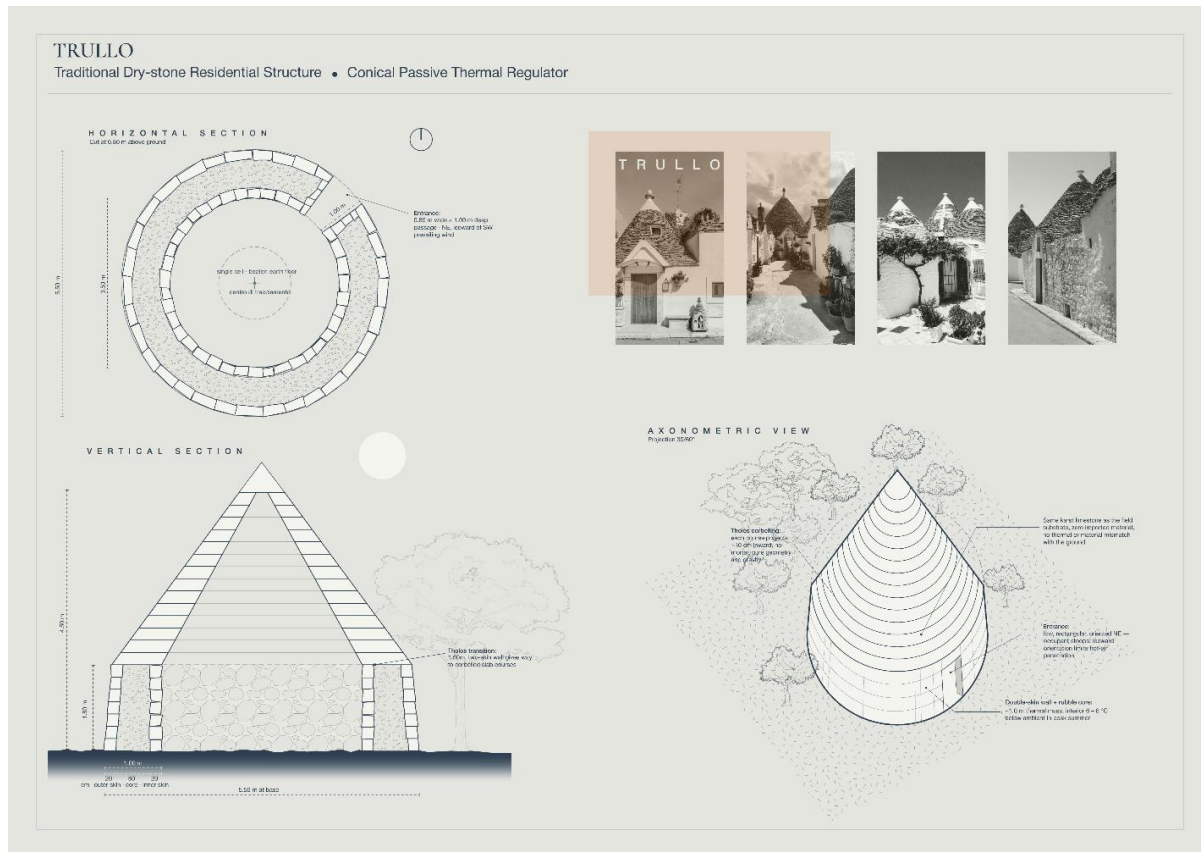


Note. Muretto

a secco as thermal and ecological infrastructure, Salento. Original illustration by the author.

Before Salento's own version of the corbelled shelter, it is worth pausing on its more celebrated Apulian relative. The trullo, the conical dry-stone dwelling of the Itria Valley, north and west of the study area, represents the most refined expression of the mortarless corbelling tradition that defines the whole region. Built without mortar from double-skin walls of calcareous limestone with a rubble core approaching a meter in thickness, the trullo resolves the same thermal problem the masseria addresses at compound scale, but reduces it to a single perfected geometry: a *tholos* in which each course of flat slabs projects roughly ten centimeters inward over the one below, closing progressively to a sealed apex. The cone is not decorative. Its mass holds the interior six to eight degrees Celsius below peak summer ambient, while its geometry establishes a convective regime that the squat agricultural shelters of the Salento would later adopt in cruder, more improvised form. The trullo is a residence; what the Salento needed was a field shelter and it built one from the same intelligence. Figure 2.16 documents this refined corbelled geometry in plan, section, and axonometric, the residential archetype against which the Salento's own agricultural shelter must be read.

Figure 2.16



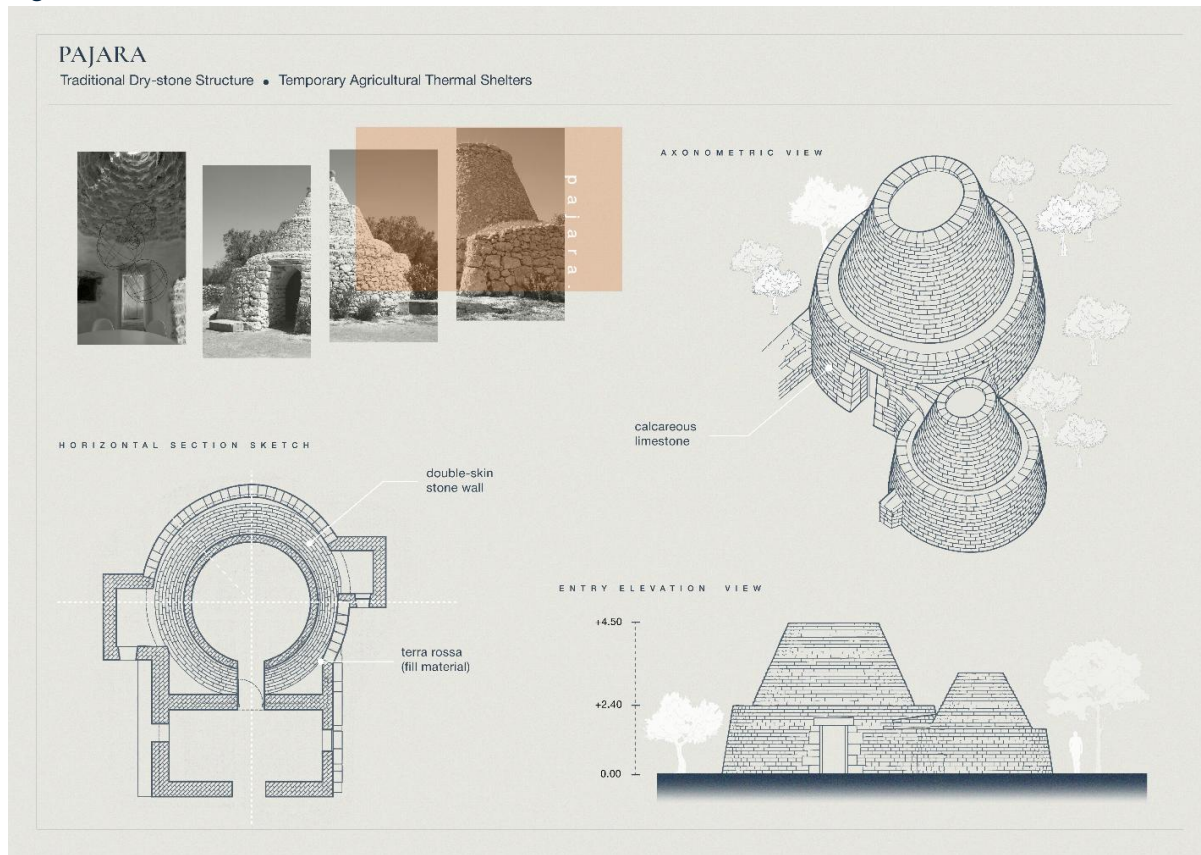
Note.

Trullo as conical passive thermal regulator, Itria Valley, Puglia (regional dry-stone reference). Original illustration by the author.

The Salento, however, did not build trulli. It built the pajara — the same corbelling principle stripped of residential refinement and reduced to its most direct agricultural expression, native to the very fringe this thesis maps. It is the most direct and pure expression of the same material intelligence as the masseria: built from the same karst limestone as the substrate, without mortar (which would trap heat in the interstitial spaces and increase thermal mass beyond what passive cooling can discharge), ventilated through the squat domed geometry and the loose stone construction that draws warm air upward while cooler air enters at the base, and sited in response to the prevailing wind regime of the specific parcel it occupies. Its construction required no imported material, no specialized technology, no design process separate from the intimate knowledge of the land itself. It is a thermally calibrated object, and its presence in a RUTZ cell is a spatial indicator of La Pietra's ecological character. In ISF analysis it registers as a negligible building footprint relative to its surrounding open karst land; in LST analysis it registers as an anomalously low-temperature point in a cell that would otherwise classify as bare-soil exposed. What it reveals is not heritage. It reveals that centuries of agricultural practice in this specific climate had already solved the thermal management problem that the RUTZ Index now attempts to formalize. Figure 2.17 makes the pajara's architecture visible in a similar scale: the corbelled stone shelter is not an artifact to be photographed but a passive thermodynamic device, its

geometry, its material, and its orientation each resolved toward a specific thermal function, readable by anyone who knows what the Salento summer demands.

Figure 2.17



Note.

Pajara as an agricultural dry-stone thermal shelter, Salento. Original illustration by the author.

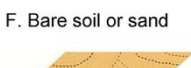
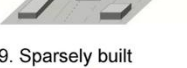
Masseria, muretto, trullo, and pajara constitute a graduated thermal intelligence operating across four spatial registers, compound, field boundary, refined residential object, and improvised agricultural shelter, each calibrated to the same limestone substrate, the same solar geometry, and the same moisture-scarce summer, and each detectable by the RUTZ Index's composite indicators at the 100m cell resolution that links architectural performance to territorial pattern. The masseria, muretto, and pajara are native to the Salento fringe; the trullo stands as its regional Apulian reference, included here not as a site-specific element but as the clearest legible expression of the corbelling logic that the Salento adapted into its own agricultural vernacular. A planning instrument that can only read these structures as built fabric, quantifying their BSF and ISF without registering their material intelligence, is blind to what makes La Pietra thermally distinctive from La Frangia. Two cells with identical BSF values but different material compositions will produce different thermal outputs: the masseria cell and the villa-block cell are morphologically comparable in their building footprint fraction, but their albedo, their moisture retention, their shading geometry, and their thermal mass are structurally different in ways that determine whether the cell functions as a climate buffer or as a heat accumulator. The RUTZ Index's albedo indicator and its LPI metric are designed to capture this difference at the composite level.

But the case for why those indicators matter, why albedo is not merely a surface characteristic but a thermal consequence of material culture, and why LPI is not merely a patch-size measure but a proxy for the climatic coherence of the landscape must be made here, in the theoretical framework, before the reader encounters them in the methodology.

2.3.4 The LCZ Framework and Its Limits in Mediterranean Heterogeneous Morphologies

The Local Climate Zone framework was introduced by Iain D. Stewart and Tim R. Oke (2012) in the *Bulletin of the American Meteorological Society* — a methodological proposal that has since become the global standard for urban climate classification. Stewart and Oke argued that the urban heat island literature had been impeded for decades by an inadequate spatial unit: the urban–rural dichotomy, in which any given study site was classified merely as "urban" or "rural" with no further articulation of the physical properties that produce thermal behavior. This binary, they observed, obscured more than it revealed. Two "urban" sites with identical zoning designations could produce radically different thermal environments, and two "rural" sites could differ as profoundly as a managed irrigated orchard differs from a bare karst plateau. To replace the dichotomy, Stewart and Oke proposed seventeen classes, ten built types (LCZ 1 through LCZ 10) and seven natural land cover types (LCZ A through LCZ G) — each defined by a measurable combination of surface structure (building height, density), surface cover (impervious or pervious fraction), and human metabolic activity. The LCZ system, operationalized at global scale through the WUDAPT (World Urban Database and Access Portal Tools) initiative, became the framework within which contemporary urban thermal research is now conducted. For a thesis concerned with the thermal performance of the rural–urban transition zone, LCZ is the obvious methodological starting point but, as the following subsections argue, it is also a framework whose internal assumptions about morphological homogeneity break down precisely where the Lecce fringe begins. The four subsections that follow trace this productive tension: 2.3.4.1 establishes the conceptual move LCZ made; 2.3.4.2 examines the geometric assumptions on which it depends; 2.3.4.3 identifies where those assumptions fail in the Mediterranean fringe; and 2.3.4.4 reads the empirical confirmation of those failures from recent Lecce-based research. The full classification scheme, ten built types and seven land-cover types, each defined by measurable physical properties is presented in Figure 2.18.

Figure 2.18

Built types	Definition	Land cover types	Definition
1. Compact highrise 	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise 	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact lowrise 	Dense mix of lowrise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub 	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open highrise 	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants 	Featureless landscape of grass or herbaceous plant cover. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise 	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved 	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open lowrise 	Open arrangement of lowrise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand 	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight lowrise 	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water 	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large lowrise 	Open arrangement of large lowrise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	VARIABLE LAND COVER PROPERTIES	
9. Sparsely built 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
10. Heavy industry 	Lowrise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	b. bare trees	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
		s. snow cover	Snow cover > 10 cm in depth. Low admittance. High albedo.
		d. dry ground	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Note. Abridged definitions for the seventeen Local Climate Zones: ten built types (LCZ 1–10) and seven land-cover types (LCZ A–G), each defined by surface structure, surface cover, fabric, and metabolic activity. LCZs 1–9 correspond to Oke's (2004) urban climate zones. Reproduced from Stewart and Oke (2012, Table 2), Bulletin of the American Meteorological Society. © American Meteorological Society. Used in accordance with AMS Copyright Information for academic non-commercial reuse with attribution.

2.3.4.1 The Ontological Shift: From Land Use to Local Climate

Stewart and Oke (2012) made the methodological move that urban climate research had long required: they shifted the classification unit from land use, an administrative and economic category, to local climate zone, a spatial category defined by the physical properties most directly responsible for the urban thermal environment. The 17 LCZ classes they proposed, ten built types and seven natural land cover types are each defined by a characteristic combination of sky view factor, building surface fraction, impervious surface fraction, pervious surface fraction, height of roughness elements, terrain roughness, and surface albedo. The ontological shift matters because land use categories (residential,

commercial, industrial) carry no thermal information: two residential zones with identical zoning designations may produce radically different thermal environments depending on their building density, materiality, and green cover. LCZ classification reads what actually produces heat, not what planning documents say a space is for.

2.3.4.2 *The Geometric Logic of the Classification*

The geometric logic of the LCZ system is calibrated to the scale at which morphological homogeneity is achievable in a consolidated urban fabric: hundreds of meters to several kilometers. Within that range, the 17 classes can distinguish between compact high-rise (LCZ 1) and open low-rise (LCZ 6), between heavy industry (LCZ 10) and scattered trees (LCZ B), capturing enough of the physical variation relevant to thermal modelling to produce useful climate maps for city-level analysis. The assumption of spatial homogeneity within classification units is the system's productive simplification. It allows global comparison, supports energy balance modelling, and scales efficiently across satellite data resolutions. It is also the assumption that the Lecce fringe violates systematically.

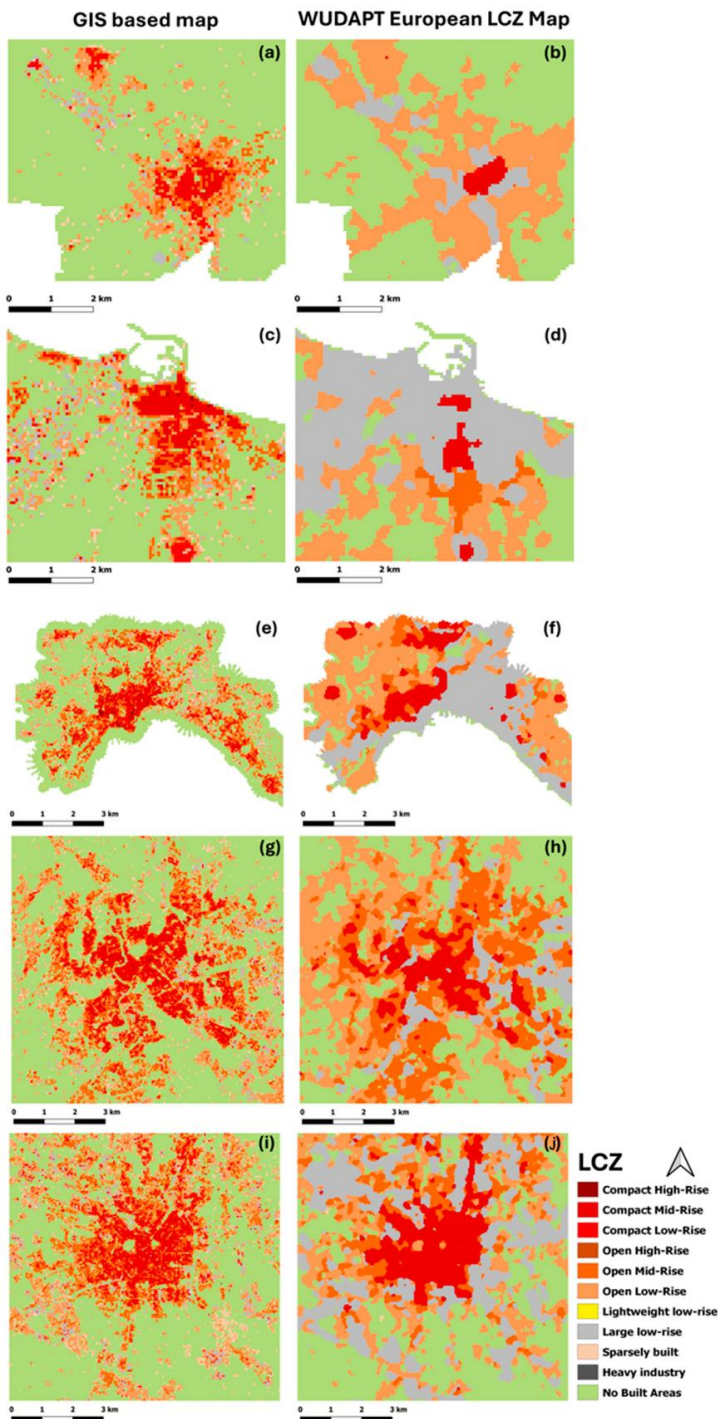
2.3.4.3 *Typological Tension in Mediterranean Heterogeneous Morphologies*

The fringe condition in Mediterranean semi-arid cities does not produce the spatial homogeneity that LCZ classification requires. A 100m cell in La Frangia may simultaneously contain a sealed villa driveway (LCZ 6 characteristics), a dead olive grove (LCZ B degrading toward LCZ F), a dry-stone wall fragment (no LCZ class), and an incomplete building foundation (LCZ 9 characteristics). No single LCZ class can represent this mosaic. The WUDAPT methodology, the standardized workflow for producing global LCZ maps through machine learning on satellite imagery assigns the cell a dominant class based on spectral similarity to training samples. In the Mediterranean fringe, the spectral signature of low-density mixed morphology consistently resolves toward LCZ 6 (open low-rise) or LCZ 9 (sparsely built), because the algorithms trained predominantly on consolidated urban typologies from higher-latitude European cities encounter a mosaic they have not been trained to resolve.

2.3.4.4 *Empirical Evidence from Lecce*

Pappaccogli et al. (2025), comparing GIS-based LCZ classification against WUDAPT classification for Lecce using high-resolution ECOSTRESS thermal data, confirms the methodological limits of the standard approach directly. The WUDAPT map overestimates LCZ 6 and LCZ 8, the open low-rise and large low-rise classes that roughly correspond to peri-urban sprawl morphologies, while underrepresenting more compact urban types. Figure 2.19 renders this divergence directly: where the GIS-based classification (left) preserves the fine-grained mosaic of the peri-urban fabric, the WUDAPT classification (right) dissolves it into smooth, oversized class blocks.

Figure 2.19



Note. Comparison of GIS-based and WUDAPT-European LCZ classifications across five urban areas, including Lecce. The WUDAPT approach systematically generalizes the fine morphological heterogeneity that GIS-based classification preserves. From Pappaccogli, G., Esposito, A., & Buccolieri, R. (2025). Summer Diurnal LST Variability Across Local Climate Zones Using ECOSTRESS Data in Lecce and Milan. *Atmosphere*, 16(4), 377. <https://doi.org/10.3390/atmos16040377>.

This is not a marginal discrepancy, it is the systematic erasure of precisely the transitional fabric that the RUTZ Index is built to read and where the heterogeneity is greatest. The Kruskal-Wallis test they apply to compare LST distributions across GIS and WUDAPT classification methodologies confirms statistically significant differences, meaning the classification methodology influences the thermal conclusions that follow from it. For Lecce's historic districts, both methods converge: the Pietra Leccese material signal is

strong enough to register consistently across classification approaches. For the fringe, they diverge and the divergence has planning consequences, because any thermal risk assessment built on a misclassified fringe map will direct intervention to the wrong spatial units.

The methodological sources of this divergence are traceable in the global LCZ literature. Demuzere et al. (2022), building a global LCZ map using a random forest classifier trained on an extensive multi-source database, find that among the ten built LCZ types, LCZ 6 (Open low-rise) achieves the highest class-wise F1 accuracy at 78%, while LCZ 1 (Compact high-rise) scores the lowest at 50%. At the global scale, the class most likely to appear in peri-urban fringe mapping is among the easiest to classify. But this global robustness conceals a local problem. The Lecce fringe is not uniformly LCZ 6. It is a fine-grained mosaic in which open low-rise residential fabric abuts LCZ 9 (Sparsely built) development and grades into natural LCZ B (Scattered trees — the olive grove matrix), and it is precisely at these class boundaries that the classification's assumptions of within-class homogeneity break down. Demuzere et al. (2019), mapping Europe into local climate zones, establish that LCZ 9 (Sparsely built) shows increased confusion with adjacent classes when input feature sets are reduced — a finding that matters here because LCZ 9 is the classification that most closely describes the intermediate condition between intact olive matrix and consolidated villa sprawl that characterizes large stretches of the Lecce fringe. Furthermore, Demuzere et al. (2019), testing the global transferability of LCZ training data across cities, demonstrate that city-to-city classification accuracy is generally poor and improves substantially only when source and target cities belong to the same urban ecoregion. A WUDAPT map trained primarily on northern and central European cities — however accurately it classifies LCZ 6 at the global mean, cannot capture the specific spectral and morphological signature of the Mediterranean fringe where LCZ 6, LCZ 9, and natural olive-grove classes are interleaved at the parcel scale. The GIS-based reclassification that Pappaccogli et al. (2025) perform is not a refinement of minor methodological imprecision. It is the demonstration that fringe classification in this climate region requires site-specific training, and that the planning consequences of not providing it are spatial rather than statistical: a map that misidentifies the thermally active cells in the fringe also misidentifies where intervention must begin.

2.3.4.5 The 100m Grid Justification

The RUTZ Index's choice of a 100m fishnet grid as its analytical unit is a direct response to this resolution problem. At 100m, each cell corresponds to approximately 1 hectare, the minimum unit at which parcel-level morphological data (building footprints, impervious surface cover, vegetation extent) from the 2019 Regione Puglia ortophoto can be combined with 10–30m satellite imagery (Sentinel-2 for vegetation indices, Landsat-8 for LST) without the misrepresentation that accompanies either finer or coarser aggregation. A finer resolution would amplify the pixel-scale noise in the thermal data; a coarser resolution would reproduce precisely the homogeneity assumption that LCZ classification imposes

and the fringe violates. The 100m cell is small enough to capture the intra-cell heterogeneity that distinguishes La Pietra from La Frangia within a single urban block, and large enough to produce stable statistical values for the composite index metrics that §2.5 introduces. The choice is not arbitrary, it is the minimum resolution at which the fringe's thermal complexity can be held rather than collapsed.

2.3.4.6 The Biometeorological Transition

The LCZ framework was designed for climate science applications operating at the atmospheric boundary layer scale, not for the pedestrian-scale biometeorological questions that a planning instrument must address. The thermal conditions relevant to a human body standing on a fringe street — mean radiant temperature, wind speed at 1.2m height, humidity — are the product of interactions between the three-dimensional built volume, the vegetation cover, and the sky view factor at the pedestrian level, none of which is adequately captured by a 2D land cover classification at 100m resolution. The RUTZ Index does not claim to replace bioclimatic assessment tools (PET, UTCI) for design-level planning. It claims to identify the cells in the fringe gradient where thermal risk is concentrated at the territory scale, providing the spatial evidence that directs more detailed biometeorological study to the right places. The LCZ system's contribution is to have established that morphological classification and thermal performance are analytically linked at the city scale. The RUTZ Index's contribution is to extend that linkage to the sub-neighborhood heterogeneity of the Mediterranean peri-urban fringe — at a resolution and with a composite indicator logic that the LCZ system was not designed to provide — so that the transition zone, before it can be defended, can first be made legible at the scale at which its thermal function actually operates.

2.4 Soil, Ecology, and the Fringe as Living Thermal System

The climate buffer that section 2.2 and section 2.3 established as the fringe's structural function does not fail through neglect alone. It fails through an active ecological collapse whose pace, scale, and irreversibility are documented in the four subsections that follow. Section 2.4.1 establishes the agricultural matrix as the buffer's primary biological component; section 2.4.2 explains evapotranspiration as the cooling mechanism that matrix performs; section 2.4.3 introduces the soil moisture regime that underwrites both; and section 2.4.4 confronts the *Xylella fastidiosa* pandemic as the disease that has eliminated, parcel by parcel, the cooling function the entire transition zone depends on.

2.4.1 Soil as Memory: Thermal Inertia, Albedo, and the Karst Substrate

The soil of the Salento fringe is not neutral ground beneath the ecological drama that occurs above it. The Pietra Leccese calcarenite — porous, pale, formed from compressed marine

organisms remains over millions of years, is an active thermal participant. Its high porosity allows moisture to migrate upward through capillary action after winter rainfall, maintaining an evaporative surface in the upper soil horizon even as the air above it desiccates into the summer drought. Its thermal inertia, the resistance to rapid temperature change conferred by its mass and specific heat capacity, damps the diurnal temperature swing, keeping the surface from reaching the extreme afternoon peaks that bare compacted soil achieves by early afternoon. Its pale color means that a substantial fraction of incoming solar radiation is reflected before it can be absorbed, establishing the foundation of the albedo advantage that section 2.2.3 documented in the built environment. These three properties are not independent: they reinforce each other in a system where the porosity supports the moisture regime that in turn supports the evaporative cooling function, while the albedo reduces the radiation load that the moisture regime must moderate. The intact karst soil of La Pietra functions as a coupled thermal system.

When that soil is sealed, by the concrete slab of a villa driveway, by the asphalt of a strada provincial access road, by the waterproofed floor of an industrial shed, all three properties are destroyed simultaneously. The sealed surface cannot breathe moisture upward; it cannot reflect effectively (asphalt albedo is far below calcarenite); and it reaches maximum temperature by early afternoon with no mechanism for relief. Oke (1987) establishes that the partitioning of net radiation across the four energy balance pathways — sensible heat, latent heat, substrate storage, and advection is determined by the physical properties of the surface. For a sealed asphalt surface in the Salento summer, the latent heat pathway approaches zero and substrate storage accumulates until the surface achieves thermal equilibrium with the solar input. The thermal difference between an intact karst soil and a sealed parking surface in the Salento summer is not a small increment in the satellite data, it is, in De Razza et al.'s (2024) mapping of the July 2022 heatwave, the gap between a Pietra Leccese surface at approximately 31 °C and a bare peri-urban soil at 42.25 °C, a differential of over 11°C produced by material properties alone, measured on the same day under identical atmospheric conditions. The soil sealing that characterizes La Frangia does not merely cover the karst. It extinguishes the thermal system that the karst supports.

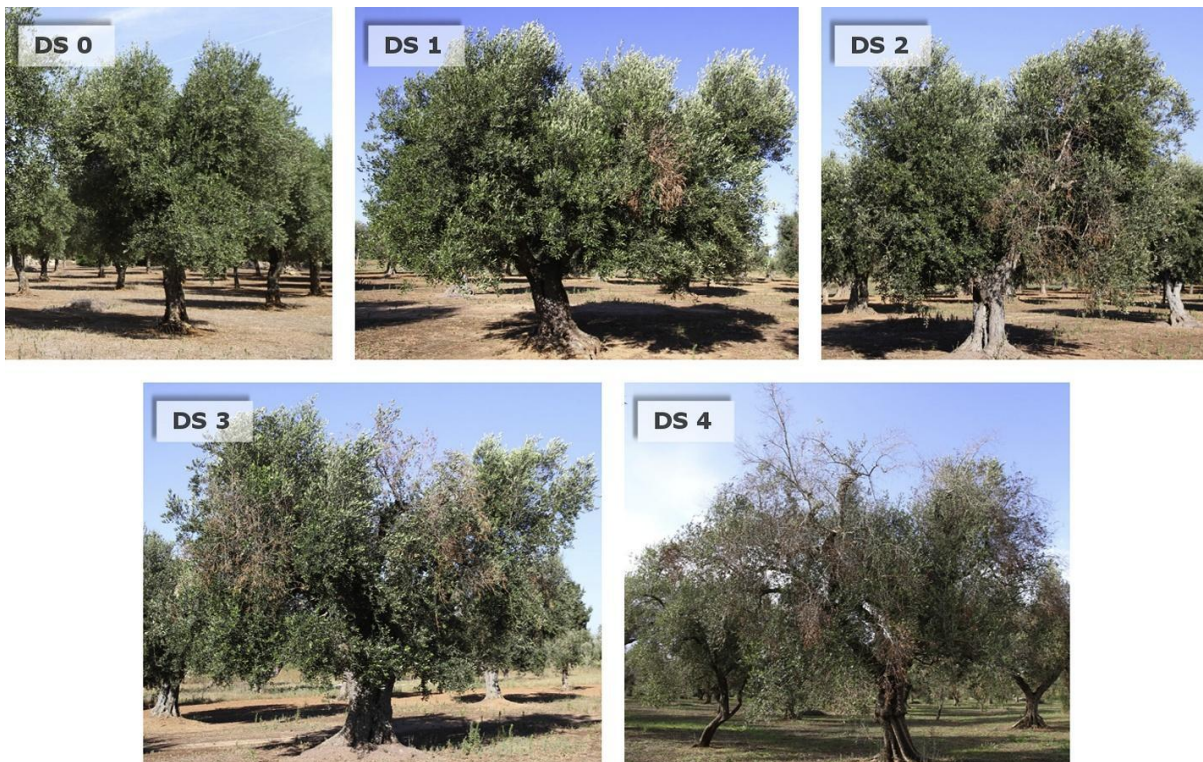
2.4.2 Evapotranspiration: The Fringe's Cooling Engine

The olive tree does something the concrete slab cannot: it sweats. That sweat, transpiration, the controlled release of moisture through leaf stomata into the boundary layer above the canopy, is the primary cooling mechanism of the Salento fringe's agricultural matrix. The energy that would otherwise heat the leaf surface and the soil beneath it is redirected into the phase change from liquid water to water vapor. The field stays cool; the air above it receives a charge of moisture that moderates the boundary layer and reduces the sensible heat flux that would otherwise warm the ambient air. The ratio that describes the competition between cooling and heating in this process, the Bowen ratio, the ratio of sensible heat flux to latent heat flux, tells the story of whether any given surface is

functioning as a thermal buffer or as a heat source. In a healthy, canopied olive grove with adequate soil moisture, the latent heat pathway dominates: the Bowen ratio is low, and the majority of incoming solar energy is consumed by evapotranspiration rather than heating the air. Qiu et al. (2013), reviewing the literature on evapotranspiration's role in mitigating urban heat, establish the quantitative range: vegetation evapotranspiration can reduce urban temperatures by 0.5 °C to 4.0 °C depending on canopy cover, moisture availability, and spatial extent — a cooling capacity that exceeds that of any passive built fabric strategy when the vegetation is intact and the moisture regime is functional.

The critical word in that formulation is intact and tells a story. When the trees die, as they die under *Xylella fastidiosa* infection, whose bacterial colonies clog the xylem, the vascular vessels that carry water from root to leaf, until the tree, though it may stand in moist soil, effectively dies of thirst, the cooling breath stops. The Bowen ratio tips toward sensible heat, and it does not tip gradually. The olive tree's evapotranspiration does not diminish proportionally with its health. It functions until the xylem is sufficiently blocked to prevent water transport, and then it stops. Hornero et al. (2020), calibrating a five-class disease severity (DS) framework from field measurements, airborne spectroscopy, and Sentinel-2 time series in Apulia's infected olive orchards, reveal that *Xylella*'s destruction of canopy function is not a spectral dimming but a physical disintegration. From DS 0 (healthy canopy) to DS 4 (very high severity — severe tree decline): Crown Leaf Area Index falls from the range 2.0–3.5 to 0.25–0.5, a reduction of up to 86%; chlorophyll content (Ca+b) drops from 65–80 µg/cm² to 10–20 µg/cm², a reduction of approximately 75–87%; fractional canopy cover (FCo) drops from 45–55% of the soil surface to a residual 5–10%. Decoded for the urban planning reader: a DS 4 canopy is no longer a canopy, it is a dispersed assemblage of dying woody stems over exposed karst soil, with evapotranspirative capacity functionally at zero. Hornero et al. (2020) document the visual signature of this progression directly: Figure 2.20 reproduces their field photographs of olive crowns across the five disease severity classes, from the intact canopy of DS 0 through the dispersed woody remnant of DS 4.

Figure 2.20



Note. Olive tree canopy condition across the five *Xylella fastidiosa* disease severity (DS) classes, from DS 0 (healthy canopy) to DS 4 (severe decline). The progression registers the physical disintegration of canopy function — leaf area, chlorophyll content, and fractional cover all collapse in parallel. Reproduced from Hornero et al. (2020, Figure 2), *Remote Sensing of Environment*, 236, 111505. © 2020 Elsevier. Reproduced with permission under RightsLink License No. 6282560229645 (issued June 5, 2026).

What the canopy parameters describe quantitatively, the photograph confirms phenomenologically: at DS 4, there is no longer a canopy in any functional sense — only a dispersed assemblage of dying wood over exposed soil.

This has a direct methodological consequence for how the collapse must be detected. Hornero et al. (2020) show that a single satellite image, taken on a single day, cannot reliably catch a grove in the early stages of decline — the bare soil between the trees and the seasonal grasses underneath confuse the signal, masking the canopy's true condition. What the satellite can read reliably is the trajectory: the same parcel observed across many years, its slow spectral drift toward exposure made legible only by time. This is why the RUTZ Index does not read a single moment but stacks the full 2015–2025 record — it is designed to catch the collapse as a process, not to photograph it as a state. The Temperature-Vegetation Dryness Index (TVDI) framework that Sandholt et al. (2002) developed for semi-arid water-limited landscapes, and which section 2.5 introduces as a diagnostic instrument for the RUTZ pipeline, reads the same collapse from the dryness side: as TVDI values in a cell approach 1, the evaporative cooling function is functionally absent. The canopy that once functioned as a distributed climatic buffer across the peri-urban fringe has been reduced, parcel by parcel, to a bare radiative surface. This is the ecological argument for why the transition zone must be measured, mapped, and defended.

The thermal consequence of this collapse is not merely local. Pappaccogli et al. (2024), monitoring heatwave dynamics in Lecce over four years, find that the stations showing the lowest urban heat island intensity are precisely those with the highest surrounding green cover and the most intact suburban vegetation, the clearest confirmation that the buffer function is ecological in nature, not geometric. When the vegetation that performs that function is removed, the buffer collapses and the UHI at nearby urban stations rises. The fringe's evapotranspirative capacity is not an amenity that the city benefits from incidentally. It is the primary mechanism through which the rural matrix performs its thermal service to the urban core. Defending that capacity is defending the service.

2.4.3 The Karst Aquifer as Subsurface Buffer

The Lecce basin sits on a coastal karst aquifer of extraordinary extent and ecological significance. The Salento aquifer, the regional groundwater body that underlies the peninsula through a highly porous and permeable carbonate rock sequence, is not merely a water supply system. It is the fringe's subsurface moisture reserve: the deep storage from which capillary action draws moisture upward through the soil column to sustain evapotranspiration through the summer drought when surface moisture has long since evaporated. Parise (2011), documenting the karst geomorphology of the Apulian carbonate terrains, describes a system in which surface and subsurface processes are tightly coupled: the porous limestone allows rapid infiltration of winter rainfall, which recharges the aquifer before the dry season, while the shallow calcareous soils maintain a capillary connection between the saturated zone and the surface vegetation through the summer. In the intact agricultural landscape, this subsurface moisture supply sustains evapotranspiration and therefore surface cooling through periods when surface rainfall is absent. The karst is not just a geological substrate. It is the fringe's water battery: the slow-discharge moisture reserve that allows vegetation to continue cooling even through the most arid summer weeks.

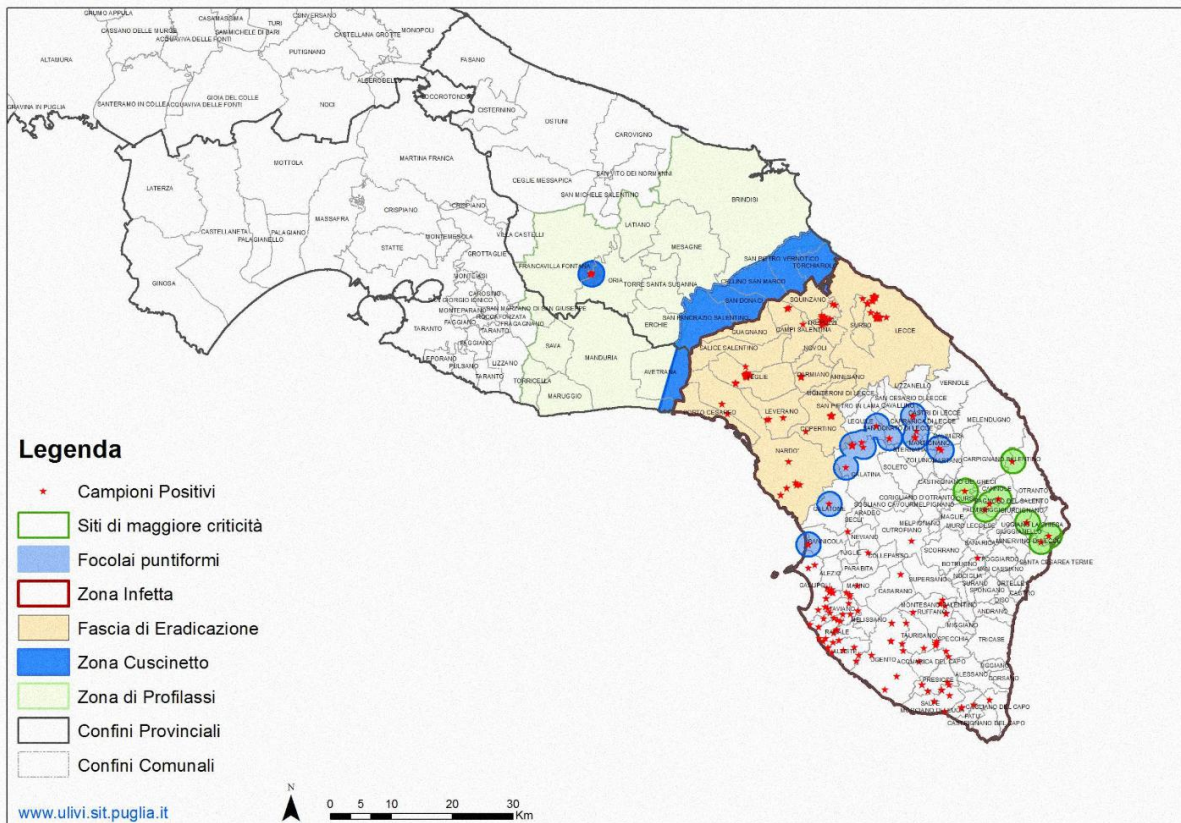
Mammadova and Negri (2024), reviewing decades of well data analysis for the Salento aquifer, document a structural decline in piezometric levels driven by intensified agricultural abstraction, expanding tourism demand, and the compounding effects of climate-driven drought intensification. Alfio et al. (2020), calculating Standardized Precipitation Index trends for the Salento peninsula from 1949 to 2011, confirm that drought frequency and severity have increased significantly across the study period, with the most severe drought events coinciding with periods of groundwater depletion and accelerated salinization. The aquifer under stress is an aquifer that can less reliably sustain the capillary moisture supply that fringe vegetation depends on and an aquifer whose recharge surface is shrinking as fringe sealing progresses. The interaction is reciprocal and compounding: drought reduces recharge, sealing reduces recharge area, abstraction lowers the water table, and the capillary connection to surface vegetation weakens. When the fringe is sealed — roads,

villas, sealed driveways — the aquifer loses the permeable surface through which winter rainfall would recharge it. The capillary moisture supply to remaining vegetation is interrupted not only by the drought above but by the sealing below. What can be understood as a Karst Dry-Island effect is produced: a sealed surface that generates thermal stress while simultaneously destroying the aquifer recharge capacity that would have allowed the surviving vegetation to compensate. The fringe's thermal degradation is not merely a surface phenomenon. It is driven from below as well as from above.

2.4.4 The *Xylella* Factor: Collapse, Not Decline

Xylella fastidiosa is not a stressor that weakens the Salento fringe's thermal function. It is a pathogen that eliminates it. Since the first confirmed detection in the Province of Lecce in 2013, the bacterium — a xylem-blocking plant pathogen transmitted through the spittlebug— has advanced southward through Salento's olive grove landscape with the completeness of an ecological catastrophe. The tree does not gradually decline in evapotranspirative output under *Xylella* infection. It dies. The xylem vessels responsible for water transport from root to leaf are blocked progressively until the tree can no longer supply moisture to its canopy, and within two to three years of severe infection the canopy collapses entirely. What had been a continuous olive grove, a working evapotranspirative system producing latent heat flux across hectares of fringe territory — becomes, within a single epidemic cycle, a landscape of dead stumps and bare karst soil. What the satellite registers across *Xylella*-affected cells is the spectral signature of fractional canopy cover collapse: from the 45–55% characteristic of a DS 0 healthy olive grove to a residual 5–10% at DS 4 very high severity (Hornero et al., 2020) — a collapse not gradual but discontinuous, tracking the xylem blockage threshold beyond which evapotranspiration ceases. The thermal consequence is not a modest upward shift in LST. It is the removal of the entire latent heat cooling mechanism from affected parcels, replaced by the bare-soil thermal regime documented in section 2.4.1: a surface with no moisture to spend, no canopy to shade it, and no reflective stone to moderate its radiation load. The map produced in the year following this certification — Figure 2.21 below — is not a scientific document but an administrative one: the Commissario Delegato's formal inscription of territorial loss into public record, the moment when the Italian state certified that a province had been consumed before the instrument to measure its thermal consequences had been built.

Figure 2.21

**Note.**

Third definition of the demarcated zones for *Xylella fastidiosa*, Province of Lecce (March 2015). Zona Infetta: entire Province of Lecce. Fascia di Eradicazione, Zona Cuscinetto, Zona di Profilassi, Focolai puntiformi, Siti di maggiore criticità also depicted. The nine thesis municipalities fall within the Zona di Eradicazione. From Piano degli interventi, OCDPC n. 225/2015, Allegato 2, Determinazione Dirigenziale n. 54 del 13/03/2015, by the Commissario Delegato per il Rischio Fitosanitario da *Xylella fastidiosa*, 2015. In the public domain. (p. 55)

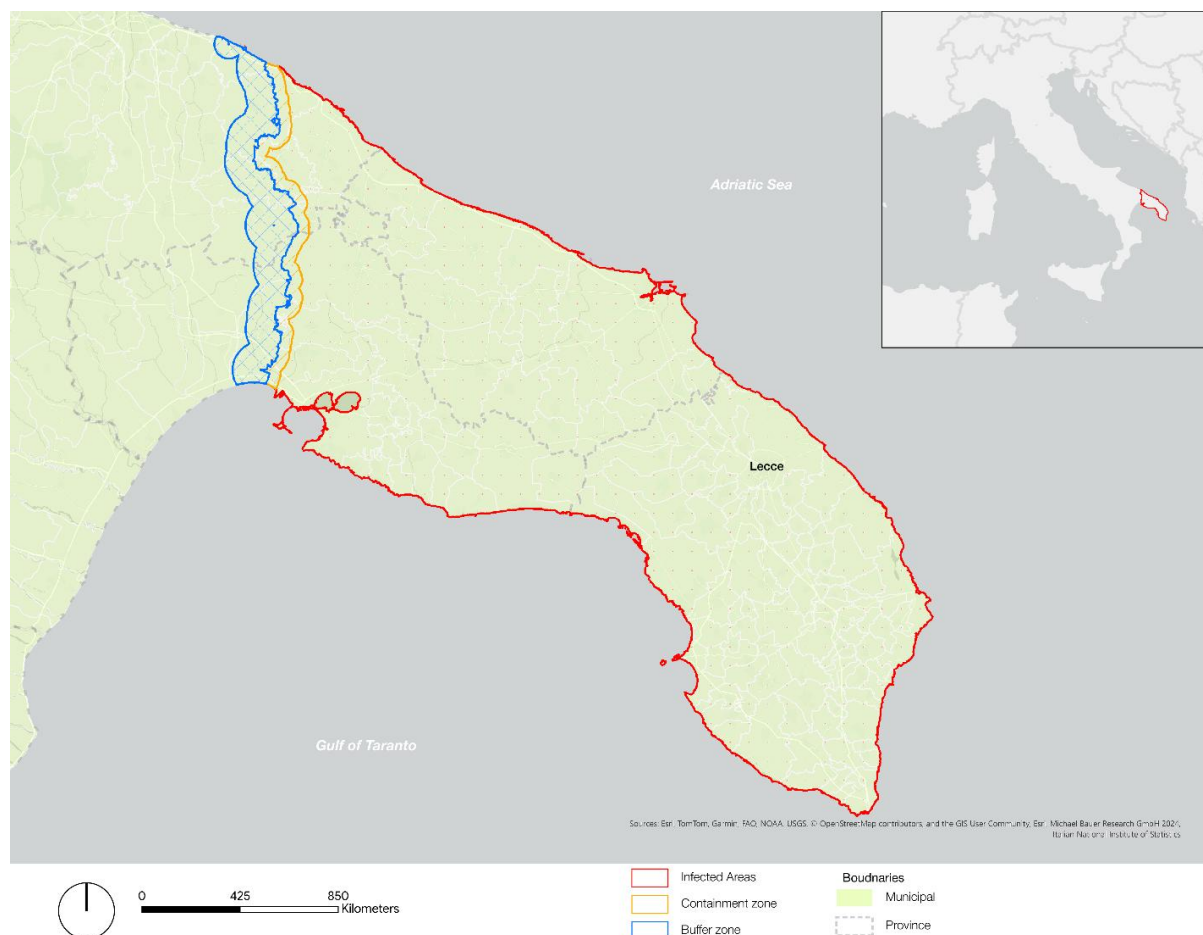
What the 2015 delimitation set in motion was not a recovery but a retreat: the management boundary moved north because the south was conceded, and the Buffer Zone that was once drawn around the Province of Lecce became, over the following decade, the operational frontier of a containment effort that had already surrendered the territory it was meant to protect.

Spatially, this collapse maps with precision onto the RUTZ Index's Three Ecologies. The Shadow is the transitional state, the landscape that has passed through the initial *Xylella* impact but retains residual biological activity in the herbaceous understory that colonizes the spaces between dead olive stumps. Its spectral signature — depressed NDVI, elevated bare-soil indices, declining temporal stability — registers exactly the transitional condition that the RUTZ classification is designed to capture, as Chapter 5 will operationalize: neither the vitality of the Stone's intact olive matrix nor the bareness of the Fire's fully exposed soil. Its TVDI values register moderate-to-high dryness stress, reflecting the loss of the deep-rooted canopy that once drew on the aquifer's subsurface moisture reserve. Its LST is intermediate but rising: the trajectory of a landscape whose cooling function has been impaired but not entirely extinguished. La Frangia, in this reading, is not merely the outcome

of sprawl. It is also the thermal destination of the Xylella collapse, the landscape that has passed through the Shadow's transitional state without recovery, arriving at the bare, sealed, thermally inert condition that the July 2022 satellite data registers as the province's hottest surface type. The three ecologies are not a static taxonomy. They are a trajectory: the Stone ecology is what the fringe was designed, over centuries, to be; the Shadow is what it becomes when the design fails; the Fire is what it becomes when the failure is complete.

Figure 2.22 is not an update of Figure 2.21, it is its spatial proof: where the 2015 map showed a Province under emergency declaration, the 2026 delimitation from the Regione Puglia Osservatorio Fitosanitario shows the Buffer Zone relocated north of the Province entirely, because the territory of the Province of Lecce is no longer a management boundary but a confirmed interior the Infected Area now extends into the provinces of Brindisi and Taranto, and the frontier of active containment has moved on.

Figure 2.22



Note. Current delimitation of *Xylella fastidiosa* infected and containment zones, Puglia Region (Determination DDS n. 82/2026, 11 May 2026). Infected Areas encompass the entire Province of Lecce and parts of the provinces of Brindisi and Taranto. Containment zone and Buffer zone mark the active management boundary in the northern Salento-Brindisi-Taranto transition. From Portale Emergenza Xylella, Regione Puglia, Osservatorio Fitosanitario, 2026.
https://www.emergenzaxylella.it/portal/portale_gestione_agricoltura/Cartografie

Read as a sequence, these two maps constitute the ecological argument for the RUTZ Index's existence: the thermal transition zone that this thesis measures and maps is not a planning abstraction but the last measurable edge of a functioning climate buffer before the *Xylella* collapse pushes the province's thermal degradation further north and the purpose of mapping it is to establish, before that edge dissolves, what is worth defending and where the defense must begin.

The *Xylella* crisis is therefore not background context for a thesis primarily about morphology and classification. It is the empirical ground for the thesis's spatial argument. Without *Xylella*, the fringe's thermal degradation would be gradual, driven by sprawl and agricultural abandonment across decades, recoverable through policy intervention at a planning timescale. With *Xylella*, the degradation is sudden, biologically driven, and territorially complete within a single epidemic cycle. The RUTZ Index is designed to read both the gradual and the sudden, because both are present simultaneously in the Lecce fringe: the slow creep of ISF across the Fire's expanding sealing footprint, and the abrupt NDVI collapse of the Shadow's dying olive parcels. Together they constitute the compound emergency that this thesis addresses, one that only an instrument designed to read both the architectural residue of a vanishing landscape and the ecological velocity of its collapse can make legible, because only such an instrument can tell the planner not just that the fringe is degrading but which cells, at what speed, and along which boundary the last defensible edge of the transition zone runs.

2.5 Quantitative Instruments of Landscape Diagnosis

The indices assembled in this section are not a methodological inventory. They are the instruments through which this thesis reads the Lecce fringe as a functioning or failing climate system. Each one occupies a specific diagnostic role in the integrated reading the thesis will construct: it measures a phenomenon that cannot be accessed by the indices on either side of it, and it contributes a dimension of understanding — thermal, biological, physical, or morphological — that the composite analysis of Chapter 5 requires. Read together, they constitute a grammar of landscape performance: not a description of what the fringe looks like from space, but a diagnosis of what it is doing with the energy, moisture, and built matter it contains.

2.5.1 Thermal Stress Indices (LST, UTFVI, TVDI)

The satellite does not measure heat. It measures what the surface has done with the energy the sun gave it, and that is a very different thing. Land Surface Temperature (LST) is the thermal output of a surface's energy balance: the quantity of solar radiation that a given patch of ground, rooftop, or canopy could not convert into evaporation, photosynthesis, or

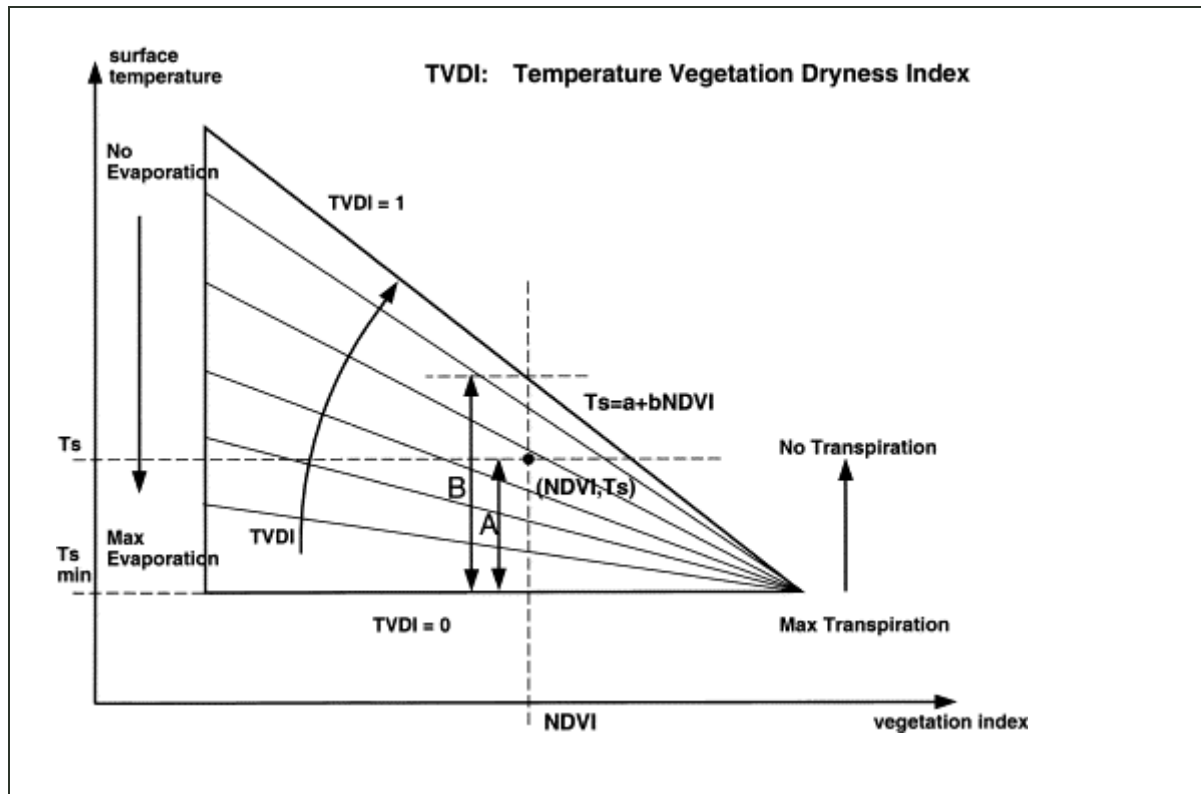
long-wave re-emission, and instead transferred into the warming of the air immediately above it. Every material in the landscape participates in this balance differently. As Oke (1987) established in the foundational account of urban boundary layer climatology, the three-dimensional geometry of the built surface, the depth of street canyons, the sky-view factor of open plazas, the thermal mass of stone walls, determines how much solar energy is trapped and how slowly it dissipates. Voogt & Oke (2003) extended this analysis to the satellite observation context, demonstrating that the directional anisotropy and emissivity variations that complicate LST retrieval are most severe in the broken surface texture of the peri-urban fringe, where sealed roads, bare limestone, and olive canopy co-exist within a single pixel footprint, each carrying a distinct thermal signature that composite-pixel temperature conceals more than it reveals.

What LST records is therefore not an abstract number but the integrated thermal biography of the landscape beneath the sensor: the cumulative outcome of every material choice, every sealed surface, every removed canopy that has shaped the surface's capacity to cool itself. Applied to the Lecce fringe, LST establishes the baseline thermal signature of the transition gradient, the raw spatial map of which cells are absorbing and which are releasing.

The Urban Thermal Field Variance Index (UTFVI) translates that raw thermal map into a spatial grammar of anomaly. Rather than reporting absolute temperature, UTFVI measures how far any given point deviates from the city's mean surface temperature, normalizing that deviation by the mean itself. What this produces is a legible field of thermal discontinuity: a negative UTFVI marks a cooling node pulling the surface below the urban average — a functioning patch of canopy, a water-retaining soil, an irrigated plot, while a positive value identifies a heat trap where the surface has broken free of the modulating influence of the surrounding landscape. Liu & Zhang (2011) demonstrated the index's capacity to stratify urban thermal environments into ecologically meaningful categories in Hong Kong, linking the highest-severity zones to concentrated impervious development. Naim et al. (2021), tracking Chattogram's urbanization trajectory from 1988 to 2018, documented one of the most striking consequences of what UTFVI can reveal over time: average LST rose by approximately 10°C across three decades, the proportion of the city's area under the strongest UTFVI classification expanded from 1.69% to 27.53%, and the causal agent was clear, the progressive replacement of vegetated and bare-soil surfaces by impervious cover (Naim et al., 2021). Applied to the RUTZ framework, UTFVI serves a precise function: it reveals not average heat but thermal rupture, the specific locations in the fringe gradient where the buffer's regulatory capacity has collapsed.

The Temperature Vegetation Dryness Index (TVDI) operates at a deeper spatial register still. Sandholt et al. (2002) developed the index by observing that, when satellite LST is plotted

against vegetation index (NDVI) for a large, heterogeneous area, the resulting scatter forms a characteristic triangle in Ts/NDVI space. Its dry edge represents the maximum possible surface temperature for each level of vegetation cover, surfaces with no evaporative cooling; its wet edge, the minimum, surfaces whose temperature is limited only by available energy. TVDI measures where each pixel sits within this thermal-ecological space: values approaching 1 mark surfaces under extreme dryness stress, their soil moisture exhausted and their evaporative capacity near-zero; values approaching 0 mark surfaces with freely available moisture and active biological cooling. What TVDI reads, in territorial terms, is the drying-out of the landscape's buffer function, a fringe where TVDI values are high is a fringe whose soils have lost their moisture-retaining ability and whose vegetation is already stressed before the heat season arrives. Sandholt et al. validated the index in the semi-arid Ferlo region of northern Senegal, a water-limited landscape where NDVI is constrained by moisture availability rather than nutrients or light, achieving $R^2 = 0.70$ between TVDI and simulated soil moisture across transects. This structural parallel to Salento, water-limited Mediterranean soils, shallow calcareous substrates, vegetation cover that collapses under summer stress, makes the index directly applicable. The critical methodological caveat is the wet-edge parameterization: Lecce's dry summers compress the lower boundary of the Ts/NDVI triangle, narrowing the index's operational range and systematically overestimating dryness stress if default wet-edge values derived from humid contexts are applied without local calibration against growing-season composites (Sandholt et al., 2002). Figure 2.23 shows the Ts/NDVI triangle and its dry- and wet-edge boundaries, making legible the parametric space within which every pixel of the Lecce fringe will be positioned.

Figure 2.23 The Ts/NDVI Triangle and TVDI Parameterization

Note. The Temperature–Vegetation Dryness Index (TVDI) triangle as defined by Sandholt et al. (2002). The dry edge (upper boundary) represents the maximum surface temperature for each NDVI level under zero-evaporation conditions; the wet edge (lower boundary) marks the minimum temperature under freely available moisture. TVDI measures each pixel's position between these extremes. The compression of the wet edge under semi-arid summer conditions — as occurs in the Salento — requires local calibration of the wet-edge parameter rather than default humid-context values. Reproduced from Sandholt et al. (2002, Figure 3), *Remote Sensing of Environment*, 79(2–3), 213–224. © 2002 Elsevier. Reproduced with permission under RightsLink License No. 6285231446532 (issued June 10, 2026).

2.5.2 Vegetation Vitality (NDVI, SAVI, NDMI)

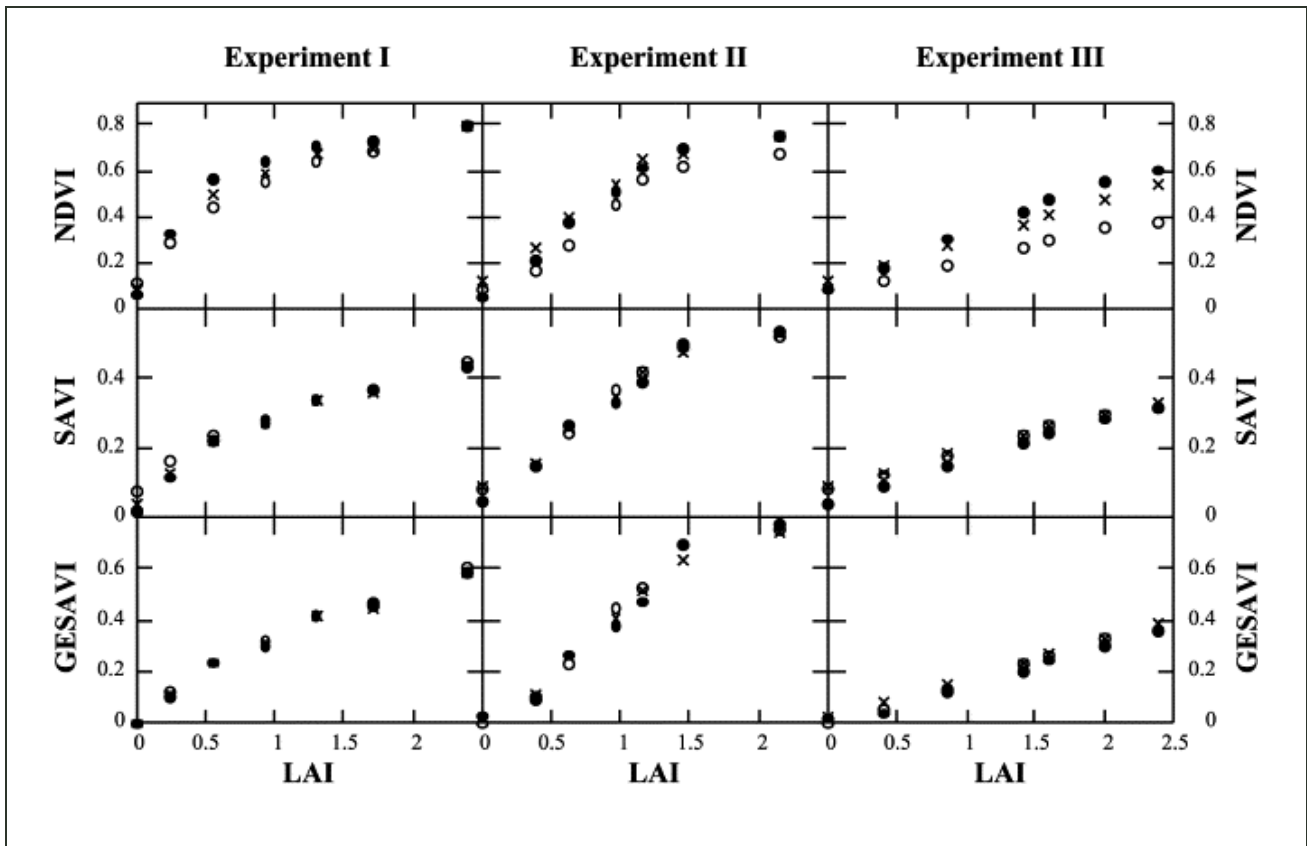
Every plant on the Lecce fringe is performing a thermal service while it lives. The olive canopies threading between the sealed roads and industrial sheds of the Salento peri-urban landscape are not merely aesthetic residuals of an agricultural past; they are active evapotranspirative machines, intercepting solar radiation, releasing moisture into the boundary layer, and reducing the sensible heat flux that would otherwise elevate surface and air temperatures. Reading the condition of this biological cooling system from space requires not one index but a diagnostic sequence, each instrument designed to overcome a specific failure mode of the one before it.

The Normalized Difference Vegetation Index (NDVI) is the foundation. Rouse et al. (1974) first formalized the ratio of near-infrared to red reflectance as a monitoring index for vegetated surfaces; Tucker (1979) subsequently demonstrated that the same ratio captures the chlorophyll-driven absorption signature of photosynthetically active biomass, NDVI

ranges from approximately –0.1 for water and bare mineral surfaces to 0.9 for dense green canopy; in practical application, values above approximately 0.3 signal meaningful vegetation, the olive grove in summer registers near 0.5–0.6, and the exposed calcareous soils of Puglia sit near 0.1–0.2. The problem begins at that boundary. Puglia's agricultural mosaic is dominated by the very soils that contaminate the near-infrared signal and inflate apparent NDVI regardless of actual canopy cover. Huete (1988) identified this failure systematically, demonstrating that standard ratio indices, including NDVI, suffer from soil brightness influences whenever vegetation cover is sparse to intermediate — precisely the condition that governs most of the Lecce fringe for much of the year. His Soil-Adjusted Vegetation Index (SAVI) corrects this by introducing an adjustment factor L that shifts the reflectance origin of the NIR-Red space: $SAVI = (NIR - Red) / (NIR + Red + L) \times (1 + L)$. Testing across cotton and range grass canopies over multiple soil backgrounds, Huete found that $L = 0.5$ nearly eliminated soil-induced variation for intermediate cover conditions, the canonical parameterization for environments like Puglia's agricultural fringe (Huete, 1988). Gilabert et al. (2002), testing a generalized extension of the SAVI family across multiple vegetation types and soil backgrounds, confirm that all SAVI-family indices substantially reduce soil-brightness noise compared to NDVI, the improvement most pronounced at intermediate cover levels where the calcareous fallow soils of the Salento dominate the spectral signal. Valdivieso-Ros et al. (2023), classifying land cover in a semiarid Mediterranean landscape in Murcia, climatically and morphologically comparable to Salento, confirm that SAVI is essential for accurately distinguishing vegetated cells from agricultural-fallow cells in a landscape where bare calcareous soil dominates spectrally across many months, achieving 91% overall accuracy only through the synergetic combination of spectral indices that include soil-adjusted reflectance (Figure 2.24).

The third index, NDMI (Normalized Difference Moisture Index), accesses a dimension that NDVI and SAVI cannot reach: the water content of the leaf tissue itself. Where NDVI reads chlorophyll activity and SAVI corrects for soil background, NDMI uses shortwave infrared wavelengths to detect canopy water stress independent of greenness. Wilson and Sader (2002) demonstrated that NDMI significantly outperformed NDVI in detecting canopy disturbance linked to moisture stress, with the SWIR band proving far more sensitive to tissue water content than the red band used by NDVI. In Lecce's specific context, this distinction is not merely methodological; it is territorial. The *Xylella fastidiosa* epidemic that has destabilized the olive grove landscape of the Salento since 2013 produces trees that may maintain a green canopy appearance in early stages while suffering from xylem blockage and internal water stress: NDVI reads these trees as healthy buffer contributors; NDMI identifies them as moisture-compromised. At the 100m fishnet scale of the RUTZ Index, the combination of NDVI and SAVI enables the thesis to distinguish actively vegetated buffer cells from spectrally confounded bare-agricultural cells, while NDMI applies the moisture-stress overlay that reveals whether the green signal reflects a functioning evapotranspirative system or a canopy already under heat-season pressure.

Figure 2.24 NDVI vs. SAVI Response Across Soil Backgrounds



Note. NDVI, SAVI, and GESAVI values as a function of Leaf Area Index (LAI) across three soil backgrounds. Reproduced from Gilabert et al. (2002, Figure 3), *Remote Sensing of Environment*, 82(2–3), 303–310. © 2002 Elsevier. Reproduced with permission under RightsLink License No. 6285241228929 (issued June 10, 2026).

2.5.3 Bare Surface, Moisture and Albedo (BSI, SMI, Bare Land Ratio, Albedo)

A landscape stripped of its vegetative cover does not become neutral. It becomes a radiator. The exposed soils and sealed surfaces of the rural-urban transition zone do not merely fail to cool, they absorb solar radiation during the day and re-emit it as long-wave heat, sustaining elevated boundary-layer temperatures long after sunset. Measuring this thermal-physical stripping of the fringe requires a family of indices that together characterize how much of the transition zone has lost its evaporative and shading capacity: the Bare Soil Index (BSI), the Soil Moisture Index (SMI), the Bare Land Ratio, and the surface albedo. Each reads a different layer of the same degradation.

The Bare Soil Index (BSI) and its variants identify the spectral signature of exposed mineral surfaces, the shortwave infrared and near-infrared combination that distinguishes bare ground from vegetated or sealed cover. Rikimaru et al. (2002) developed an early BSI formulation within a forest canopy density model; Nguyen et al. (2021) refined this into the Modified Bare Soil Index (MBI), using SWIR and NIR wavelengths from Landsat 8 to resolve the persistent challenge of separating bare soil from spectrally similar urban fabric — rooftops, light-colored paved surfaces — during agricultural fallow periods. Across

validation sites in Thailand and Vietnam, the MBI achieved approximately 98% overall accuracy, demonstrating that the SWIR-NIR combination can resolve the spectral ambiguity that characterizes the Lecce fringe, where limestone rooftops and bare calcareous fields sit within the same pixel and appear nearly identical to a conventional index. The Bare Land Ratio complements BSI at the cell-aggregate level, quantifying the fraction of each 100m fishnet unit that presents as spectrally bare, a direct proxy for the degree to which that cell has been stripped of its participation in the moisture cycle.

The Soil Moisture Index applied in the RUTZ pipeline follows the Temperature Condition Index logic formalized by Kogan (1995): $SMI = (LST_{ma}^x - LST) / (LST_{ma}^x - LST_{mi}^n)$, where the spatial thermal range of the study area substitutes for the multi-year temporal range used in regional drought monitoring. The instrument operates on a principle that is the inverse of thermal stress: where surface temperatures approach the observed maximum, where evaporative cooling has failed and solar energy is converted directly into sensible heat, SMI approaches zero; where temperatures are suppressed toward the observed minimum by active evapotranspiration or retained soil moisture, SMI approaches one. In the shallow calcareous regosols of Salento, where the summer gradient from moist to fully desiccated soil is steep and spatially abrupt, this thermal proxy captures a moisture-stress signal that spectral band ratios cannot access: the suppression of cooling that occurs before surface reflectance has changed enough to register in NDMI.

NDMI and SMI are therefore not redundant instruments measuring the same phenomenon through different wavelengths. They are complementary diagnostics operating at different points in the moisture cycle: NDMI reads the water content of the material directly; SMI reads the thermal consequence of that water content's absence.

Albedo, the fraction of incident solar radiation that a surface reflects to the atmosphere, is where this diagnostic family reaches its most direct expression of radiative budget. A surface with high albedo absorbs less incoming solar energy; a low-albedo surface converts more of it into surface heating. Liang (2001) established the foundational narrowband-to-broadband conversion algorithms for deriving broadband albedo from multispectral satellite reflectance — the mathematical bridge between discrete spectral bands and the total reflected radiation required by energy balance calculations. The difficulty, as Baldinelli et al. (2017) demonstrated through a field-validated study in Perugia, is that these standard algorithms considerably underestimate high albedo values in the urban context, producing RMSE values of 0.07–0.08 that exceed acceptable thresholds for energy-balance applications. The standard conversions assume a surface spectral signature calibrated on rural or natural land covers, an assumption that collapses in cities where rooftops, road surfaces, and bare soils each carry distinctive spectral shapes. This problem intensifies in Lecce. Pietra Leccese limestone, the building material of the historic center and the geological substrate of the Salento peninsula, produces anomalously high albedo values in exposed surfaces: rooftops, dry-stone walls, and bare agricultural fields on limestone substrates all register elevated reflectances that standard algorithms systematically

misinterpret. Barletta et al. (2022) extended albedo algorithm validation specifically to Bari (Southern Italy), comparing Landsat 8 and Sentinel-2 retrievals over Southern Italian urban fabric in Google Earth Engine and finding sensor-specific accuracy variations across land-cover classes, with noticeable RMSE differences tracking precisely the light-colored built and bare surfaces characteristic of the Apulian city. Barletta et al. (2023) confirmed strong consistency between Landsat 8 and Landsat 9 albedo retrievals for the region, and Barletta et al. (2024) demonstrated that albedo change analysis can track urban land consumption in the Apulian municipality of Bitritto with 92% overall accuracy, establishing the methodological validation chain from algorithm calibration to urban growth monitoring within the territorial context that surrounds Lecce's peri-urban fringe. The cells in the RUTZ fishnet where BSI is elevated, SMI is depleted, and albedo is anomalous are precisely the cells where the buffer has ceased to function, where the fringe has become, thermally, an extension of the city rather than its mitigation.

2.5.4 Morphological Configuration (BSF, ISF, NP, MESH, ENN)

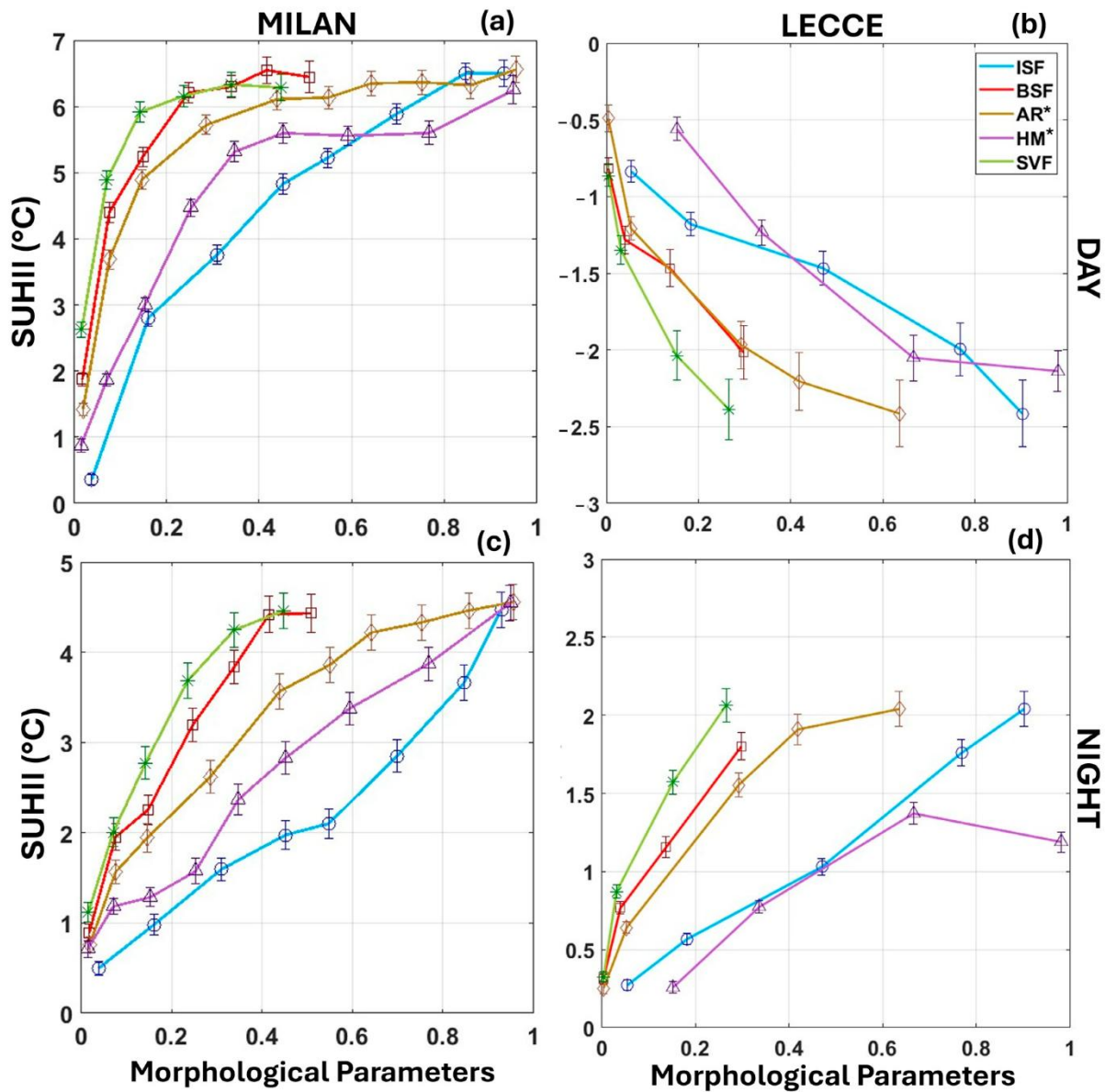
Heat does not distribute itself randomly across the urban fringe. It follows a geometry, the geometry of buildings that trap it, the geometry of open ground that might release it, and the geometry of the patches between them that determine whether the thermal exchange can travel far enough to matter. Spectral indices read the surface's thermal and biological condition; morphological indices provide the structural skeleton onto which that condition is inscribed. They translate the physical arrangement of built mass and open land into measurable spatial quantities that can be correlated, regressed, and mapped at the same resolution as the indices that read their thermal consequences.

The Spacematrix framework, developed by Berghauser Pont and Haupt across successive editions, including the revised 2023 volume, provides the foundation for characterizing the built mass itself within the RUTZ pipeline. Its key instruments are the Building Surface Fraction (BSF), the proportion of a unit's total area covered by building footprints and the Impervious Surface Fraction (ISF), the proportion sealed against infiltration by both buildings and paved surfaces. Where traditional density measures collapse spatial complexity into a single number, Berghauser Pont and Haupt (2023) demonstrate that traditional single-variable density measures fail to convey actual urban density, arguing that a multivariable approach captures the interactions between floor area, coverage, and height that single-parameter descriptions cannot express. For the RUTZ Index operating at the 100m fishnet scale, ISF and BSF are not only built-density descriptors, but they are indicators of the proportion of each cell that has been removed from the moisture cycle that sustains the fringe's evaporative buffer function. The ecological counterpart of this density vocabulary comes from the FRAGSTATS tradition established by McGarigal & Marks (1995): the Number of Patches (NP), which measures fragmentation in its simplest spatial form; the Effective Mesh Size (MESH), formalized by Jaeger (2000) as the area-proportionately additive

measure of patch continuity, expressing the probability that two randomly placed points within a landscape belong to the same patch; and the Euclidean Nearest Neighbor distance (ENN), which captures the isolation of each patch from its nearest equivalent, the physical distance the fringe's cooling signal must travel before reaching another functioning buffer unit.

The empirical baseline for deploying these indices in Lecce comes from four studies that together constitute the thermal morphology literature for the Salento context. Esposito et al. (2024), analyzing over 1,000 Sentinel-3 LST images from 2022 and 2023, systematically identified ISF as the primary morphological driver of Surface Urban Heat Island intensity (SUHI) in Lecce. After removing multicollinear variables, the finding arrives with a counterintuitive result of direct importance to this thesis: Lecce's average daytime SUHI is negative (-1.08°C), the urban core is actually cooler than the surrounding agricultural landscape in summer. This Surface Urban Cool Island effect reflects the thermal reality of a semi-arid Mediterranean context where the dry, bare rural land surrounding the city reaches higher temperatures than the urban fabric during the peak heat season. It reveals a dynamic that standard UHI analysis systematically misses: in Lecce, the fringe can be the site of greatest thermal risk, not the city center. Esposito et al. (2025) extended this analysis to a four-city Italian comparison, Lecce, Bari, Milan, and Turin, using multiple linear regression across more than 1,000 Sentinel-3 summer images. ISF, Leaf Area Index (LAI), and surface albedo emerged as the most influential predictors of SUHI across all cities, with the Lecce and Bari pair structurally distinct from the northern cities in their lower or negative diurnal SUHI and their heightened sensitivity to vegetation cover and albedo rather than built density alone (Esposito et al., 2025). At the city-municipal scale, Valente et al. (2022) document Lecce's Urban Green Index at 26% and Green Connectivity Index at 21% using FRAGSTATS-based landscape metrics, quantifying the ecological configuration against which the RUTZ Index must be read. Lovello et al. (2025) extend this spatial analysis to the broader Salento context, documenting significant urban sprawl across Lecce, Galatone, and Nardò between 2006 and 2022, with approximately 47% of Lecce's land area classified as degraded and degraded surfaces progressively encroaching on the natural areas that constitute the ecological basis of the fringe's climate-modulating potential. These four studies together constitute the empirical coordinates within which the RUTZ Index operates, and the baseline against which its 100m fishnet outputs will be positioned. Figure 2.25 presents the ISF–SUHI regression from Esposito et al. (2024) that anchors the negative daytime SUHI finding and its morphological explanation.

Figure 2.25 ISF–SUHI Regression for Lecce and Milan



Note.

Daytime and nighttime SUHII as a function of Impervious Surface Fraction (ISF) for Lecce and Milan (summer 2022–2023). Lecce's negative daytime SUHII values, the urban core being cooler than surrounding agricultural land, confirm ISF as the primary morphological driver of the thermal gradient and reveal the Surface Urban Cool Island dynamic unique to semi-arid Mediterranean contexts. This inversion is the empirical foundation of the RUTZ Index's fringe-centered thermal diagnostic. Reproduced from Esposito et al. (2024, Figure 2) under CC BY 4.0.

2.5.5 Index Integration: Toward a Multi-Scalar Composite Diagnostic

No single index reads the thermal condition of the Lecce fringe completely. The surface temperature tells you how hot a cell is; it does not tell you whether the heat originates from

an impervious surface, a dying olive grove, a bare limestone field, or an unmixed spectral combination of all three. The vegetation signal tells you something is green; it does not tell you whether that green is actively cooling or passively present. The morphological indices tell you how the built mass is arranged; they do not tell you what the unbuilt spaces between the buildings are contributing or failing to contribute to the energy balance. Reading the fringe as a climate system demands an instrument that holds these domains simultaneously: a composite diagnostic capable of expressing the interaction of spectral, morphological, and ecological variables at the same spatial resolution.

The intellectual precedent for this integration is now established across several bodies of urban climate research. Yuan & Bauer (2007), analyzing multi-seasonal Landsat data for the Twin Cities metropolitan area in Minnesota, demonstrated that the relationship between LST and percent impervious surface area is strongly and consistently linear across all four seasons, while the LST-NDVI relationship is weaker, non-linear, and season-dependent. Their conclusion, that impervious surface area provides a complementary metric to the traditionally applied NDVI for analyzing LST quantitatively over the seasons, makes the methodological case for combining structural and biological signals into a single diagnostic rather than relying on either alone (Yuan & Bauer, 2007). Nardino et al. (2022) advanced this integration further with the Urban Heatwave Thermal Index (UHTI), applied to Bologna, Italy, during a summer heatwave: a composite of land surface temperature, Vegetation Fractional Cover (VFC, derived from NDVI), and Sky View Factor (SVF) operating at 10m resolution. Their analysis found that SVF contributed 40–45% of the composite signal, LST 30–35%, and NDVI the remainder, with a high correlation between the UHTI and the standard UTFVI. Crucially, Nardino et al. (2022) demonstrated that single-index UTFVI flags the dense historic center as the worst thermal hotspot, while the UHTI — incorporating morphological shading through SVF- reveals that it is actually cooler than the exposed open periphery. This inversion is precisely what the Lecce fringe demands: a city where the cool island sits in the dense urban core and the heat accumulates in the morphologically open, biologically degraded transition zone. Ferreira et al. (2021), mapping heat-vulnerable areas in São José dos Campos, Brazil, constructed a 60×60m cellular spatial model integrating LST, NDMI, fraction of vegetation cover, albedo, and LCZ classification, a direct methodological precedent for the RUTZ fishnet diagnostic, demonstrating that heat-vulnerable areas are most accurately identified not through any single indicator but through the spatial coincidence of high LST, low canopy moisture, low albedo, and specific morphological configurations. The composite spatial index is not a methodological refinement — it is the minimum level of diagnostic precision that the spatial complexity of the fringe demands.

The second and more critical argument this sub-section must make is that the dominant existing framework for urban thermal classification, the Local Climate Zone (LCZ) system, is insufficient for the Lecce peri-urban fringe, and this insufficiency is not a calibration problem but a structural mismatch. Stewart & Oke (2012) developed LCZ to standardize the description of urban surface structure and cover across 17 canonical types, offering a

common typological vocabulary for urban temperature research. The framework has genuine utility for morphologically homogeneous urban contexts, the compact continuous city center, the low-density residential suburb, where built geometry and land cover co-vary predictably enough that a zone type produces a consistent thermal signature. The Lecce fringe is none of these. It is a landscape dominated by LCZ 9, the sparsely built type, where irregular villa aggregations, agricultural remnants, limestone quarry sites, abandoned olive groves, and informal construction intermingle at spatial frequencies finer than the LCZ's minimum mapping unit.

Demuzere et al. (2019), testing the transferability of LCZ models across cities and ecoregions using Google Earth Engine, found that city-to-city mapping results are generally poor unless training data derives from a city within the same ecoregion as the target, immediately undermining any assumption that LCZ classifiers trained on northern European or East Asian cities can be applied to a semi-arid Southern Italian fringe without systematic error. The specific accuracy statistics reported by Ren et al. (2019) make the problem precise: across more than 20 Chinese cities following the standard WUDAPT method, building classes achieved a mean accuracy of only 48%; LCZ 9, the sparsely built class, achieved the lowest accuracy of any class, averaging just 32% (Ren et al., 2019). Sparsely built is not a peripheral condition in the Lecce fringe; it is its dominant morphological character. Manyanya et al. (2024), working in Cape Town, reveal that the problem runs deeper than classifier accuracy: LCZ has been documented not to result in distinct thermal environments at the surface level per LCZ class in sparse, low-rise cities. The classification may be internally consistent as a typological description, but the thermal differentiation it promises, the core rationale for deploying it in UHI analysis, breaks down where building height data is scarce, morphology is heterogeneous, and the thermal response of each zone type overlaps with its neighbors.

The gap these findings expose is not incidental. It is structural, and it is specific to the morphological condition of the Lecce fringe. It is the gap between what existing classification frameworks can resolve, the thermal typology of morphologically homogeneous, data-rich urban cores, and what the Lecce fringe gradient demands: a sub-cell diagnostic capable of reading thermal behavior at the resolution where morphological configuration, soil moisture, vegetation vitality, and radiative balance interact in ecologically meaningful ways. This is precisely the methodological space the RUTZ Index is designed to occupy. The formal characterization of that gap, the articulation of what the existing literature cannot resolve and what a new instrument must therefore provide, is the work of Chapter 2.6. The geoprocessing workflow through which these indices are computed, normalized, and combined into the RUTZ composite is documented in Chapter 5; the heat-risk and demographic vulnerability analyses operating on administrative units are deferred to Chapter 8.

2.6 Synthesis: Identifying the High-Resolution Gap

Five lines of inquiry have crossed the same territory from five directions, and the work of this closing section is to show that they arrive, together, at a single unanswered question. Section 2.1 dismantled the binary map and reframed the fringe as a thick, porous membrane across which heat, water, and capital move in both directions (Allen, 2003)—a hybrid landscape that the diffuse-city tradition reads as productively urbanized (Donadieu, 2013; Viganò et al., 2018) and the anthropology of supermodernity reads as a scatter of non-places (Augé, 1995), the two conditions interleaved so finely that no categorical boundary can hold them apart (Mortoja & Yigitcanlar, 2022). Section 2.2 states that the membrane inside a climate is amplifying faster than the global mean (Lionello & Scarascia, 2018) and shows that in the semi-arid Salento the amplification produces an inversion: the fringe, stripped of its canopy, now burns hotter than the limestone city it surrounds (De Razza et al., 2024). Section 2.3 established that this thermal behavior is not accidental but morphological, that built form, materiality, and configuration govern how a surface partitions the sun's energy (Oke, 1987; Berghauser Pont & Haupt, 2023), and that the vernacular intelligence of the masseria and the *muretto a secco* survives in the data as measurable thermal performance. Section 2.4 located the buffer's active mechanism in the living tissue of the landscape, the evapotranspirative breath of the olive canopy (Qiu et al., 2013), the capillary moisture of the karst aquifer (Parise, 2011)—and recorded its abrupt, discontinuous extinction under *Xylella fastidiosa* (Hornero et al., 2020). And Section 2.5 assembled the mature toolkit, thermal, spectral, and morphological indices—through which each of these phenomena can be read from orbit.

Laid end to end, the five sections describe a territory that is theoretically named, physically explained, morphologically structured, ecologically alive, and technically legible. And yet the instruments do not sum to the territory. Each tradition illuminates one face of the fringe and goes dark on the others. The reason is not a shortage of rigor in any single field; it is that the Lecce fringe is constituted precisely in the interaction that the existing frameworks hold apart.

That failure is specific, and it compounds in three ways. The first is a problem of integration. The morphological lineage measures built mass but is mute on the dying grove beside it; the vegetation indices read greenness but cannot see the sealed driveway; the thermal indices register the output but not its cause. Each domain, morphology, ecology, and thermal performance is treated as a separate analytical object, whereas the diagnostic precedents gathered in section 2.5 demonstrate that heat vulnerability in this kind of terrain is never a single indicator but the spatial coincidence of several (Yuan & Bauer, 2007; Nardino et al., 2022; Ferreira et al., 2021). No existing index folds morphology, ecology, and thermal behavior into one reading of buffering capacity. The second is a problem of resolution. The dominant global standard for urban thermal classification, the Local Climate Zone system and its WUDAPT operationalization (Stewart & Oke, 2012), was built for the morphologically homogeneous urban core, where built geometry and land cover co-vary predictably across

hundreds of meters to kilometers. The Salento fringe violates that premise below the scale of a single hectare: one cell may hold a sealed villa apron, a *Xylella*-killed grove, a fragment of dry-stone wall, and an unfinished foundation, four thermally distinct surfaces that the classifier averages into one. The empirical record is unambiguous. WUDAPT dissolves the fine peri-urban mosaic into oversized class blocks (Pappaccogli et al., 2025); the sparsely built class that most nearly describes the fringe is classified at roughly a third accuracy (Ren et al., 2019); training data do not transfer across ecoregions (Demuzere et al., 2019); and in sparse, low-rise contexts, the LCZ classes do not even produce distinct thermal environments at the surface (Manyanya et al., 2024). The standard fails exactly where the fringe lives. The third is a problem of time. Every classification framework assumes the land cover it maps will still be there to be mapped—and the *Xylella* collapse has falsified that assumption at territorial scale, converting a continuous canopy into bare radiative soil within a single epidemic cycle (Hornero et al., 2020). A single-date classification photographs a state that is, in this landscape, already a trajectory; it cannot register the velocity of a buffer in freefall.

Stated as one proposition, the gap is this: no existing instrument measures the buffering capacity of the rural–urban transition zone at the resolution and along the coupled morphological, ecological, and thermal dimensions that its degradation demands. It is at once a resolution gap— the fringe is too fine-grained and too heterogeneous for the LCZ cell and an integration gap—no single index reads morphology, ecology, and thermal performance as the one interacting system they physically are. The two failures are not separable because the fringe’s buffering capacity is itself the product of that interaction at that resolution.

Naming a gap, however, is not the same as filling it, and the instrument that would fill it cannot be assembled directly from a literature review. Before the morphological, ecological, and microclimatic lineages that this chapter has deliberately kept apart can be made to measure a single quantity, they must first be welded into a single conceptual frame—one in which urban form is understood as a climate instrument, the fringe as the territory most in need of that instrument, and ecological performance as urban infrastructure rather than its opposite. That welding is the work of Chapter 3: to convert the inherited concepts surveyed here into owned analytical instruments, and to assemble them into the Five Research Pillars through which the remainder of the thesis reads the Lecce fringe. Only once that conceptual apparatus is in place can the index itself be specified. The transition zone of Lecce is a climate buffer measurable, mappable, and, for now, still standing; what remains is to build the conceptual and methodological apparatus capable of measuring it, and of defending it, before the last defensible edge of the buffer dissolves.

Chapter 3

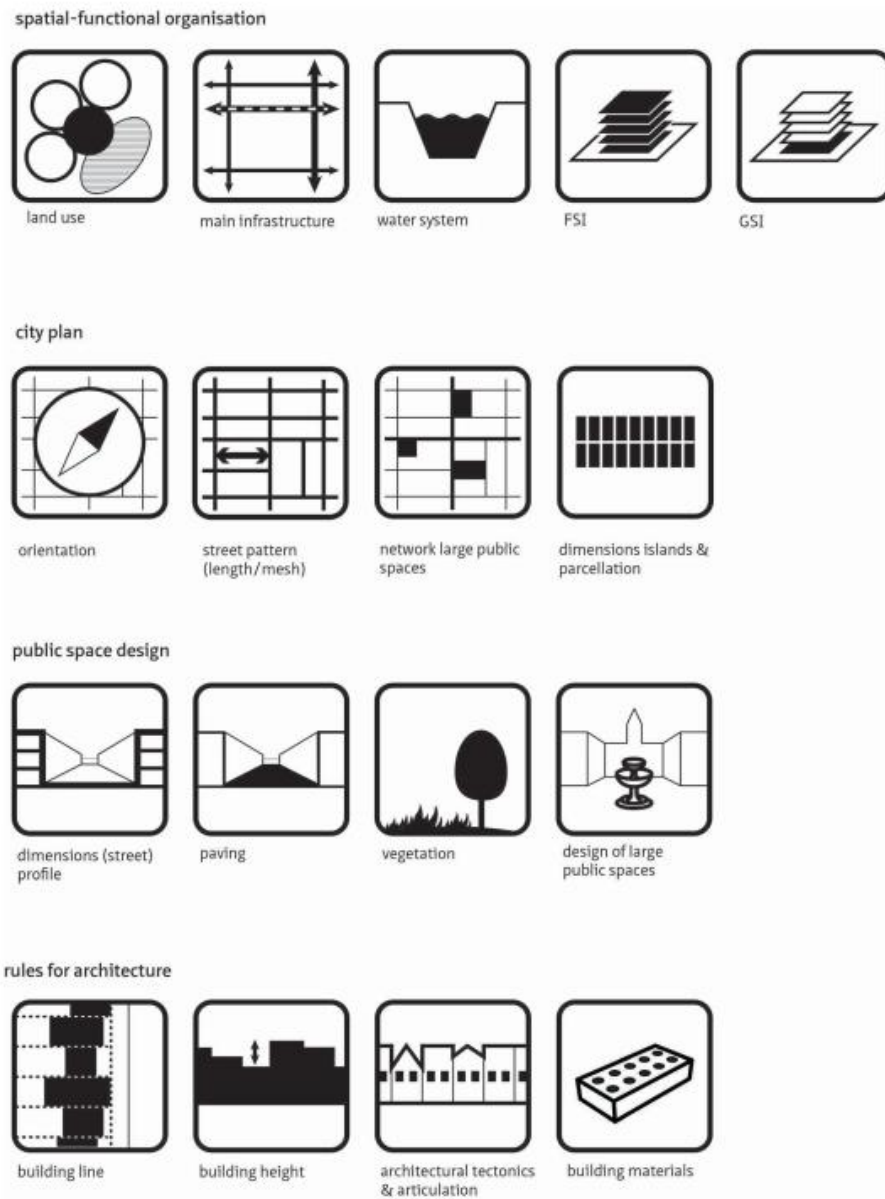
Chapter 3: Theoretical Framework

3.1 Pijpers-van Esch: The Precedent of Translation

Marjolein Pijpers-van Esch opens her 2015 doctoral dissertation at Delft University of Technology with a deceptively precise diagnosis of a professional pathology. She identifies a “remarkable discrepancy” in the practice of urban design: virtually all practitioners consider the urban microclimate to be a significant consideration in their work, and yet a majority of them seldom, if ever, collect information on it (Pijpers-van Esch, 2015, p. 20). This is not a failure of motivation. It is a structural failure of translation; the science of urban microclimatology speaks at a level of technical precision and physical abstraction that the iterative, visual, constraint-managing process of urban design cannot easily receive. Pijpers-van Esch’s dissertation is an intervention in that communication failure. Organized in three parts — first, an analysis of how urban designers work and how they use expert information; second, a rigorous review of how the built environment physically conditions every dimension of the urban microclimate; and third, a framework for a design-decision support tool that bridges both fields— her research does not merely catalog the relationship between urban form and climatic performance. It demonstrates that this relationship is legible, communicable, and, crucially, designable.

The conceptual instrument through which Pijpers-van Esch makes this demonstration is the plan element, the vocabulary of spatial decisions that urban designers already deploy in their daily practice: the Floor Space Index (FSI), the Ground Space Index (GSI), building orientation, street canyon dimensions, the disposition of vegetation. What her research shows, through field interviews with Dutch urban designers and systematic numerical simulation, is that these familiar design parameters are not merely formal categories describing what a neighborhood looks like. They are climate levers. An increase in FSI, the ratio of total floor area to site area, raises the global solar irradiation yield of the urban fabric and drives the Urban Heat Island effect; a corresponding reduction in GSI, the fraction of the ground surface covered by building footprints, decreases the exposed surface available to radiation and increases wind shelter (Pijpers-van Esch, 2015, Ch. 7). Orientation determines whether a street canyon channels or obstructs prevailing winds, whether building facades accumulate or dissipate solar energy across the diurnal cycle. Every decision the urban designer makes about where to build, how densely, at what height-to-width ratio, and in what orientation is simultaneously a decision about the microclimate of the spaces that will form between those buildings, whether the designer knows it or not. Pijpers-van Esch makes that simultaneity not only visible but actionable.

Figure 3.1 Plan Elements Overview Page, Design-Decision Support Tool



Note. Plan elements overview page from Pijpers-van Esch's design-decision support tool, displaying the vocabulary of spatial decisions, Floor Space Index, Ground Space Index, orientation, vegetation — which her framework translates into climate intelligence. The RUTZ fishnet grid operationalizes this same vocabulary at the scale of the peri-urban gradient. From *Designing the Urban Microclimate*, by M. Pijpers-van Esch, 2015, Doctoral dissertation, Delft University of Technology, Figure 6.5 (p. 230). Copyright 2015 M. Pijpers-van Esch.

The practical instrument she proposes, the design-decision support tool, is organized around a navigable matrix that places climate elements on one axis and plan elements on the other, enabling a designer to ask, at the earliest phases of the design process when the fundamental spatial choices are still open: if I adjust this parameter of my plan, what are the climatic consequences? The tool's most important innovation is not computational but epistemological. Pijpers-van Esch identifies four aspects of knowledge that require

translation for this matrix to function: complex physical phenomena must be expressed in spatial rather than purely physical terms; knowledge of separate microclimate elements must be integrated so that conflicts and agreements between design decisions become legible; the incongruity between the parameters used by microclimatological science and the plan elements used by urban designers must be systematically mapped; and the information presented must be oriented toward design generation rather than post-hoc evaluation (Pijpers-van Esch, 2015, Chapter 6.3). What she is describing, in the language of this thesis, is the productive site between measurement and spatial decision, the site where a fluency in both registers becomes not a luxury but the necessary condition of climate-sensitive practice.

It is precisely this site that the RUTZ thesis occupies, one scalar level higher. The fishnet grid, the 100 m cellular mesh that this thesis deploys across the nine municipalities of the Lecce province, is, in the logic established by Pijpers-van Esch, a spatial taxonomy of plan elements applied at the scale of the peri-urban gradient. Each cell is a morphological unit: characterized by its Building Surface Fraction, its Impervious Surface Fraction, its NDVI, its Land Surface Temperature, the same fundamental vocabulary of form and surface that Pijpers-van Esch uses for the urban neighborhood, expanded to include the ecological and thermal dimensions that emerge at the fringe. The RUTZ Index that this thesis constructs is, in this sense, a Mediterranean extension of the Pijpers-van Esch framework: it takes her foundational demonstration that morphology is a climate instrument and asks what that demonstration means when applied not to the scale of the individual neighborhood but to the full gradient from urban core to agricultural hinterland, across the transitional zone where the thermal stakes are highest and the planning attention has, historically, been most sparse. There is, however, a necessary recalibration. Pijpers-van Esch worked in the Dutch temperate climate, where the design challenge is predominantly one of maximizing solar gain, moderating wind exposure, and extending the period of outdoor thermal comfort into the colder months. The Lecce fringe presents the inverse thermodynamic condition: a Mediterranean semi-arid landscape under chronic summer heat stress, where the failure of morphological intelligence produces not a deficit of warmth but an excess of it, where the sealed road surface and the fragmented olive grove do not collaborate in a gradient of moderate temperatures but collide in a zone of thermal rupture. The translation this thesis makes from Pijpers-van Esch's precedent is therefore not only a question of scale but of climatic inversion: the same morphological logic, recalibrated for a territory where the buffer is not a mechanism for trapping heat but for managing its release.

"If Pijpers-van Esch establishes that urban morphology can be read as a climate instrument, Donadieu, Clément, and Sordi establish that the peri-urban fringe is the territory where that instrument is most urgently needed and most systematically neglected."

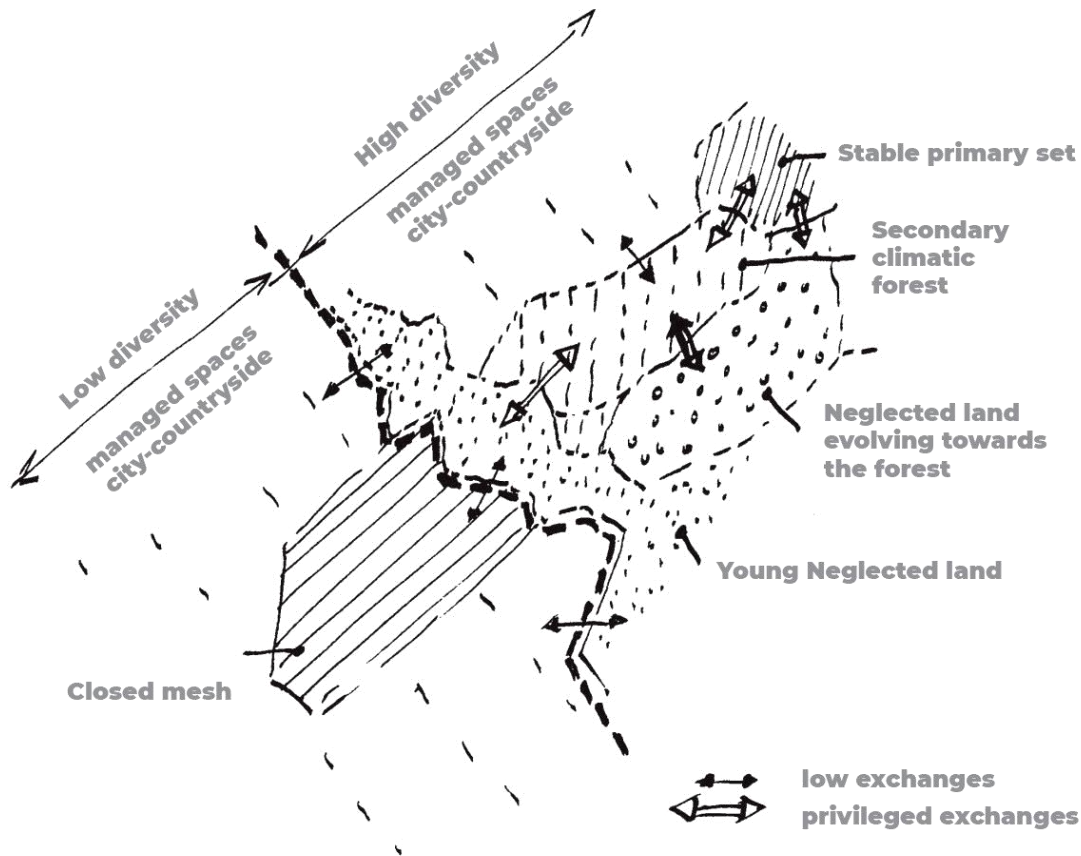
3.2 Donadieu, Clément, and Sordi: The Precedent of the Buffer Itself

Pierre Donadieu's *campagne urbaine* — developed through successive editions from the original French publication in 1998 to a first Italian edition in 2005 and a second Italian edition curated by Mariavaleria Mininni, who contributed a prefazione titled “Abitare il territorio e costruire paesaggi,” published by Carocci in 2013 — performs an act of naming that carries precise consequences for planning theory. In the dominant spatial imagination of the twentieth-century city, the peri-urban agricultural fringe appears as a residual zone: the space that remains to be urbanized, the land that the logic of expansion has not yet reached, the territory that waits in ambiguous suspension between its agricultural past and its urban future. Donadieu refuses this residualism with a rigor that is, at its core, metabolic. His foundational taxonomy frames the *campagne urbaine*'s functions along three axes: an economic function (the production of goods and the creation of employment), a spatial function (acting as a structural barrier against unchecked urban sprawl), and a symbolic function (serving landscape-oriented and commemorative purposes) (Donadieu, 2013, p. 12). As the argument matures from these three axes toward what he calls a “multifunctional public infrastructure” model, the operational outputs multiply: fresh food supply via short supply chains (Donadieu, 2013, pp. 4, 31, 138), the recycling of the city's organic waste, pedagogical services, and the provision of recreational corridors, all formalized by page 138 into a single, architecturally precise concept. The agricultural space is not a planning gap; it is, in Donadieu's definition, “una infrastruttura naturale di interesse pubblico, allo stesso titolo di una strada, di una diga, o di una rete elettrica” (a natural infrastructure of public interest, on the same footing as a road, a dam, or an electrical grid) (Donadieu, 2013, p. 137). The term is not metaphorical and is not casually introduced. On page 33, the emerging planning consensus had already been framed as a drive to “conservare l'agricoltura come un'infrastruttura verde della città,” and on page 138 Donadieu specifies that “il concetto di infrastruttura spaziale agricola chiama in causa sia le pubbliche amministrazioni che gli agricoltori”, it demands governance from both municipal administrators and the farmers who work the land. Critically for this thesis, Donadieu's infrastructure argument extends explicitly into the thermal register. Already on page 4, enumerating the systemic advantages of integrating agricultural activities into the broader green networks of urban regions, he identifies the “regolazione microclimatica delle isole di calore urbane... grazie all'imboschimento e agli spazi acquatici” (microclimatic regulation of urban heat islands, achieved through afforestation and the maintenance of aquatic spaces) as a direct and operational output of the cultivated fringe. On page 20, this biophysical claim is restated: the vegetative and aquatic surfaces of agricultural fringes contribute to the “purificazione del microclima urbano” (purification of the urban microclimate). The thermal buffer argument, in other words, is not an inference overlaid on Donadieu's text by this thesis; it is explicitly theorized within it, positioned as one of the measurable outputs that justify municipal investment in the preservation of agricultural space. Applied to the Lecce case, this reframing has immediate territorial consequences: the olive groves threading the urban fringe, the dry-stone walls organizing the agricultural parcels, the uncultivated margins

between road and orchard are not planning anomalies awaiting resolution. They are the material fabric of a natural public infrastructure, one whose microclimatic regulation functions are being extinguished parcel by parcel as the fringe mineralizes. The RUTZ Index takes Donadieu's reframing as its territorial premise: before it can measure the fringe, it must recognize it as something worth measuring as infrastructure, not residue.

Gilles Clément's Manifesto of the Third Landscape, first circulated in 2003, published in its final form in 2004, takes Donadieu's productive reframing and radicalizes it. Where Donadieu argues that the fringe is a useful metabolic category, Clément argues that it is the most ecologically precious one on the contemporary planet. The Third Landscape, "space expressing neither power nor submission to power" (Clément, 2004, p. 5), comprises precisely those territories that escape the logic of productive optimization governing both the managed city and the managed countryside: the abandoned agricultural margins, the roadside embankments, the residual patches of uncultivated ground that the machinery of efficiency cannot reach and therefore cannot simplify. These spaces accumulate biological diversity not despite their marginal status but because of it. They are, in Clément's formulation, the refuge territories of the contemporary landscape, the sites where the accelerating planetary loss of species and ecological complexity is, provisionally and quietly, interrupted. For the peri-urban fringe specifically, Clément identifies a spatial dynamic of acute urgency: as urbanization extends outward from the urban core, it closes the territorial "meshes"- the gaps and corridors through which species move, disperse, and maintain genetic exchange. "On the outskirts of large cities, urbanization closes the meshes. Furthest from the large cities, the meshes remain open" (Clément, 2004, p. 20). The closure of a mesh is not merely a visual change in the landscape; it is the severing of biological continuity, the irreversible fragmentation of the ecological network that allows the fringe to function as a living system rather than a collection of isolated patches. In the Lecce fringe, this mesh-closure is already underway: the radial expansion of residential villa development from the historic center, the progressive fragmentation of the olive grove by infrastructure and informal construction, the replacement of the agricultural margins with sealed surfaces that neither absorb nor transpire, all of these are precisely the mesh-closing operations that Clément's spatial logic identifies as the mechanisms of ecological impoverishment. The RUTZ Index, when it maps the transition from urban to rural using NDVI gradients and impervious surface fractions, is operationalizing Clément's mesh analysis: it is measuring the degree to which the biological continuity of the fringe has been preserved or compromised, cell by cell, across the gradient.

Figure 3.2 Mesh Diagram: Closed Mesh (Peri-Urban) vs. Open Mesh (Rural)

**Note.**

Clément's spatial diagram contrasts the closed mesh of the urbanizing peri-urban fringe (low biological exchange, low diversity) with the open mesh of the rural territory (privileged exchanges, high diversity). The diagram provides the spatial logic for the claim that "on the outskirts of large cities, urbanization closes the meshes" (Clément, 2004, p. 20). In the Lecce case, the RUTZ Index's NDVI and impervious surface fraction maps are the empirical measures of this closure. From *Manifesto of the Third Landscape*, by G. Clément, 2004, Trans Europe Halles, pp. 22–23. Copyright 2004 G. Clément.

Jeannette Sordi's *Beyond Urbanism* (2014) completes the arc by providing the disciplinary infrastructure that allows the RUTZ thesis to function as a planning instrument rather than merely an ecological survey. Sordi traces the genealogy of landscape urbanism from its foundational encounter between landscape architecture and urban planning at the University of Pennsylvania in the 1980s, Ian McHarg's ecological planning method, James Corner's reformulation of that method in terms of operative landscape processes, the subsequent theoretical programs of Charles Waldheim, Mohsen Mostafavi, and their collaborators, to arrive at a fully articulated intellectual tradition in which ecological processes are understood as urban infrastructure rather than its antithesis (Sordi, 2014). This is the disciplinary bridge that the RUTZ thesis requires. Without it, the measurement of NDVI gradients or evapotranspiration rates in the Lecce fringe remains a remote sensing exercise, a study of vegetation health that carries no planning authority. With it, those same measurements become planning evidence: they demonstrate the performance or failure of urban infrastructure, and they demand a planning response proportional to what is at stake. The integration of ecology into urbanism's conceptual vocabulary, the move from "nature

as the city's outside" to "ecology as the city's metabolic substrate" — is precisely what enables the RUTZ Index to speak simultaneously to the spatial planner, the landscape architect, and the climate scientist. Sordi's genealogy also furnishes a direct territorial precedent: the atlas of landscape urbanism projects in *Beyond Urbanism* includes the Urban Plan of Lecce among the cases that demonstrate the theory's potential for southern Italian territories (Sordi, 2014). Crucially, the full atlas entry, the *EcoLecce Future Urban*, a new Urban Plan for 23,836 ha, designed by Mosè Ricci and Luigi Maniglio with S. Favargiotti, L. Mazzari, E. Sommariva, and J. Sordi herself, University of Genoa, reveals that the author of *Beyond Urbanism* was not merely theorizing about the Salento from a distance; she was one of the designers who attempted to operationalize landscape urbanism on that very territory (Sordi, 2014). The disciplinary tools being imported into this thesis have already been applied, in nascent form, to the city whose fringe it is examining.

Taken together, Donadieu, Clément, and Sordi execute a single argumentative movement in three acts. Donadieu names the fringe as a natural public infrastructure, reframing it from residual to intentional, and from aesthetically marginal to thermodynamically essential. Clément proves that it is the territory of maximum ecological value, the last refuge of biological diversity in an increasingly optimized landscape, and the space whose mesh-closure produces the most irreversible ecological damage. Sordi gives the discipline the vocabulary to treat it as urban planning's legitimate subject, integrating ecology into the spatial instruments of the city and anchoring that integration to a specific territorial precedent in the Salento itself. The sequence is not arbitrary: it moves from the fringe's function (what it does for the city's metabolism and microclimate) to its value (what it harbors that no other territory can recover) to its instrument (what the discipline can build to protect and restore it). Having traversed this arc, the thesis possesses both what Chapter 3.1 set out to acquire, a methodological precedent for reading morphology as climate intelligence, and what the three theorists of Chapter 3.2 have now provided: a territorial identity for the fringe that gives that methodological precision a subject worthy of it. The analytical architecture capable of holding these two inheritances together, the Five Pillars through which the Lecce transition zone will be examined, is the task to which the following chapter turns.

Chapter 4

CHAPTER 4: Research Design and Methodological Framework

Part II of this thesis turns from what the transition zone is to how it can be made measurable. This chapter is the methodological constitution; it establishes why each decision was made, before Chapter 5 documents how each was executed. Nothing in the pipeline that follows is arbitrary; every indicator, every grid cell, every normalization is here given its justification in advance. The distributional findings the method produces, how many cells fall into each band, how the ecologies populate the territory, and how the thermal record sorts them, belong to the empirical chapters of Part III. This chapter sets the instrument; the next chapter builds it; Part III reads what it sees.

4.1 Research Approach: Measuring a Territory That Must Also Be Read

A thermal margin cannot be apprehended by measurement alone, nor by interpretation alone. The 42.25 °C that Landsat recorded on the bare peri-urban soil of Lecce in July 2022 is a number; the reason that number sits beside an abandoned olive grove, a half-finished villa block, and a severed dry-stone wall is a story. This thesis is built on the conviction that the two are inseparable — that the fringe becomes legible only when the quantitative instrument and the critical reading are held in the same hand. The research approach is therefore deliberately hybrid: a quantitative, GIS-driven analysis fused with a critical urban geography reading of the same territory. Neither is subordinate. The numbers locate the conflict in space and grade its intensity; the reading explains why the conflict is there and what it does to the people who live inside it.

This fusion is not a methodological compromise between two disciplines that distrust each other. It is the only stance from which the thermal margin is visible. A purely positivist analysis would produce a map of surface temperatures and call the hottest cells "anomalies", never registering that the anomaly is an inhabited landscape of speculative abandonment. A purely interpretive critical geography would name the conflict eloquently and never demonstrate, in degrees Celsius per hectare, that it matters thermally. The RUTZ Index is designed to refuse that choice. It is a quantitative instrument built to be interpreted; its per-cell values are not the end of the analysis but its evidentiary spine, the thing the critical reading stands on when it argues that the fringe of Lecce is a climate resource being consumed without being measured.

The approach inherits its central methodological permission from Pijpers van Esch (2016), whose work demonstrated that urban morphology is not a passive consequence of microclimate but an active, designable modulator of it, and that the gap between climate science and spatial design is a productive site of original research rather than a void to be eliminated by simplification. The RUTZ thesis occupies that same gap one scalar level larger, translating morphological and ecological intelligence into planning-actionable buffer logic for an entire fringe gradient rather than a single neighbourhood. It inherits its interpretive

ambition from Banham (1971), who proved that a territory becomes legible only when read as a set of distinct ecological systems, each with its own spatial logic and its own relationship between inhabitation and heat. Stone, Shadow, and Fire are Lecce's three ecologies in Banham's sense, and the methodological task of this thesis is to give that reading its measuring instrument, so that what Banham did with prose for Los Angeles can be done with a 100-meter grid for the Salento fringe.

The design is, in the conventional taxonomy, a mixed-method, embedded case study with a comparative-by-gradient logic. The case is the peri-urban fringe of Lecce, sampled by a continuous fishnet at a uniform 100-metre resolution. The embedded units are the individual cells of that fishnet, and the comparison is not between bounded sub-areas but along the gradient that the fishnet captures, from the deep agricultural matrix, through the contested peri-urban interface, into the consolidated urban fabric of the historic core. Quantitative analysis dominates the construction of evidence — morphological metrics, fragmentation statistics, ecological composition, and a multi-season thermal record — while the qualitative critical reading governs the interpretation of what that evidence means for a landscape under simultaneous pressure from sprawl, agricultural abandonment, and the *Xylella fastidiosa* collapse. The two strands are not run in parallel and stapled together at the end. They are interleaved at every analytical decision because the questions this thesis asks, does the fringe buffer the city, and is that buffer being lost, are at once empirical and political.

4.2 The Transect as Spine: A Continuous Gradient, Not a Comparison of Limits

The study area is the peri-urban fringe of Lecce. It is not the sum of nine municipalities, and it is not analysed as such. To treat each municipality as a discrete case and rank them against one another would be to reinstate exactly the administrative logic this thesis exists to dissolve: the assumption that the line on the cadastral map is also a line in the thermal field. The fringe does not stop at a municipal boundary. Heat, moisture, sealing, and abandonment move across those boundaries continuously, and the analytical frame must move with them. Municipal geometry will reappear in Chapter 8, where it is the natural unit for the demographic and Heat Risk Index analyses that require census-section aggregation; in Chapters 4 through 7, it is set aside in favour of the cell.

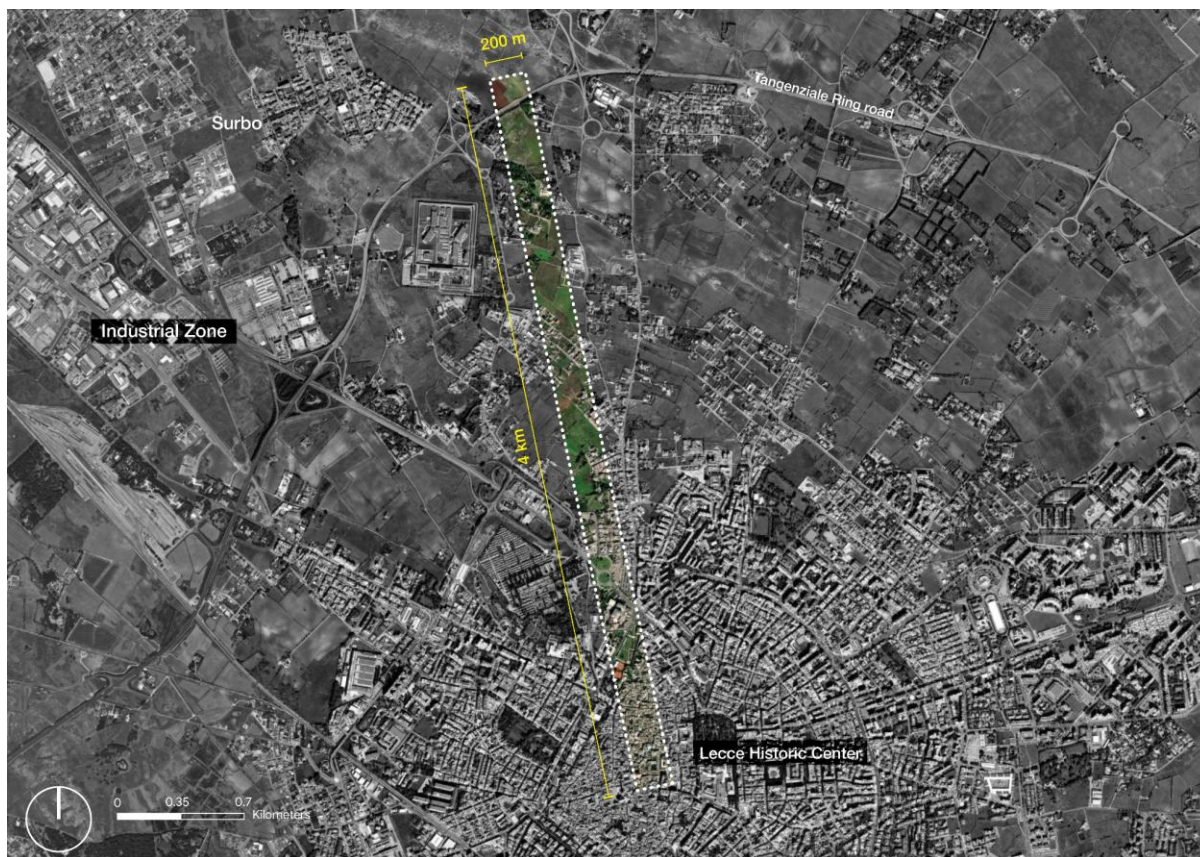
The spatial logic is therefore organised around two scales of the same gradient. The wider frame is the fishnet itself, a continuous 100-meter grid covering the peri-urban interface around the city of Lecce, including the Tangenziale ring corridor, the industrial fringe, the diffuse villa landscape that thickens between Lecce and its satellite towns, and the surviving karst-and-olive matrix that lies beyond. The grid is not partitioned into nine sub-fields; it is treated as a single continuous population whose internal variation is read along the gradient

from rural matrix to urban core. Within that wider frame, a single privileged cross-section gives the gradient its readable spine: a north-south peri-urban transect that begins at the Tangenziale ring road and the industrial zone north of the city, descends through the contested edge where peri-urban sprawl meets surviving agricultural fabric, crosses the discontinuous urban tissue of the inner ring, and terminates in the dense Pietra Leccese core of the historic centre.

The transect is the thesis's core sample, the line along which Stone, Shadow, Fire, and the Transitional gradient can be read in sequence as a single ecological journey. Where the wider fishnet provides the statistical population in which patterns appear, the transect provides the narrative section: the same per-cell measurements re-read as a profile across a real and conflicted landscape, where the inversion from cooling matrix to burning fringe can be plotted against distance rather than asserted as a claim. The transect is not a comparison case; it is a reading line. It is where the multi-season thermal record, the morphological metrics, the wall density, the ecological composition, and the critical urban geography of the conflict can be held in the same view and given a continuous spatial argument.

This sampling logic is the operational consequence of laquinta and Drescher's (2000) foundational insight that the peri-urban is not a land use but a process — dynamic, heterogeneous, defined by the simultaneous presence of incompatible spatial logics. A process cannot be sampled at discrete administrative points; it must be sampled across its full range at a resolution fine enough to register its transitions. A continuous fishnet, read along a transect spine, is a resolution made analytical. It captures the process where it is most intact, where it is most violently in flux, and where it has resolved into consolidated urbanity, the full arc of the transition in a single, uninterrupted field.

Figure 4.1 Study area and transect location



Note. Aerial composite of the Lecce peri-urban interface, north-south transect corridor overlaid from the Tangenziale ring road / industrial zone at the top through the urban edge to the Lecce historic centre at the bottom.

4.3 The 100-Metre Fishnet: Why One Hectare Is the Unit the Fringe Demands

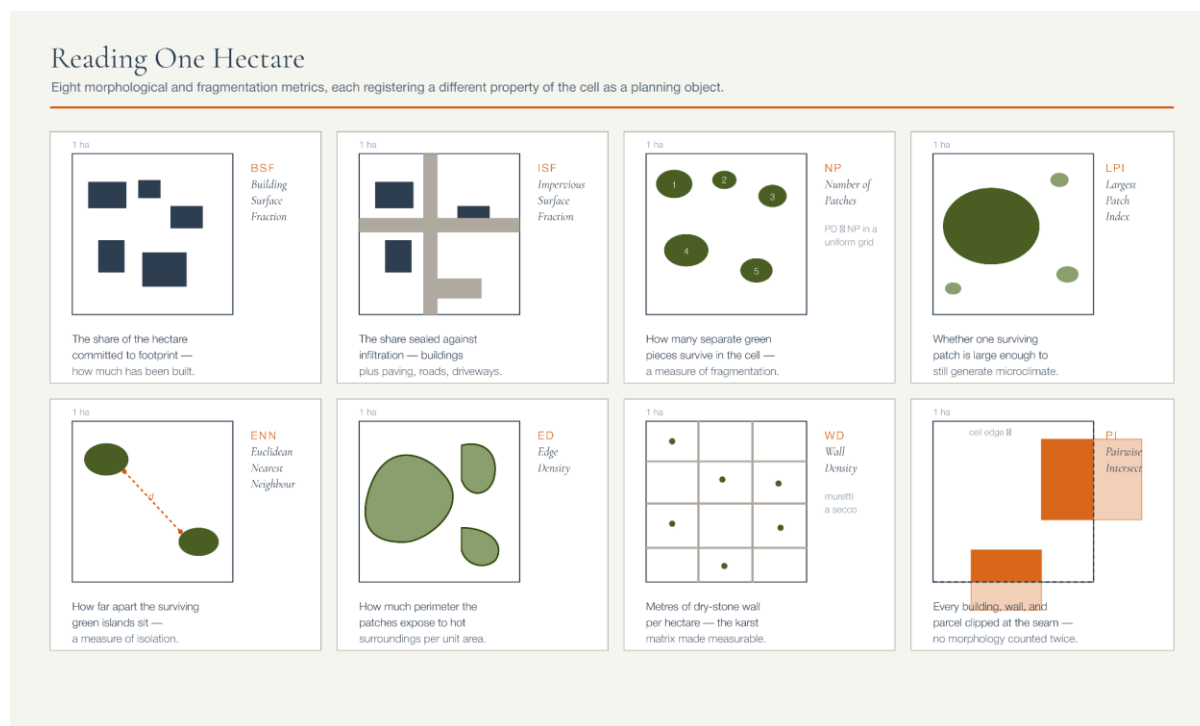
Every analytical instrument has a scale at which it tells the truth and scales at which it lies. For the Lecce fringe, that scale is one hectare. The thesis adopts a 100-metre by 100-metre fishnet, the entire peri-urban study area gridded as a single continuous field of 1-hectare cells, not as a convenient default but as the considered resolution of the entire argument. The choice is bounded by two directions, and the territory itself sets both bounds.

From below, the grid cannot be finer than the data it integrates without manufacturing false precision. The morphological metrics are derived from the 2019 Regione Puglia high-resolution orthophoto at roughly half-metre resolution; the spectral and thermal indices derive from satellite imagery at ten to thirty metres. The 100-metre cell is the smallest unit at which parcel-level building footprints and metre-scale walls can be combined with thirty-metre Land Surface Temperature without the coarser layer's pixels bleeding meaninglessly across the finer geometry. A thirty-metre fishnet would inherit the noise of the thermal sensor; a ten-metre fishnet would imply a thermal precision the satellite never delivered. One hectare is where the layers meet honestly.

From above, the grid cannot be coarser than the heterogeneity it is built to capture. This is the resolution at which the standard classification frameworks fail, where the Local Climate Zone system, calibrated to neighbourhood-scale homogeneity, collapses a cell containing a sealed driveway, a dead olive grove, an incomplete villa foundation, and a dry-stone wall fragment into a single typological label and erases precisely the variation that matters. The 100-metre cell is small enough to hold the intra-block conflict between Stone and Fire that the LCZ framework dissolves, and large enough to yield statistically stable values for the composite metrics rather than the pixel-scale flicker of a finer grid. It is the minimum resolution at which the fringe's thermal complexity can be *held* rather than averaged away.

The eight metrics that read this hectare are introduced graphically in Figure 4.3 and discussed throughout this section as planning signals rather than as environmental outputs.

Figure 4.2 Reading One Hectare: the morphological-fragmentation stack.



Note. Eight metrics, each registering a different planning property of the cell: how much has been built (Building Surface Fraction), how much sealed against infiltration (Impervious Surface Fraction), how many green pieces survive and how they are configured (Number of Patches, Largest Patch Index, Edge Density, Euclidean Nearest Neighbour), the vernacular climate infrastructure threading the karst matrix (Wall Density), and the seam-clipping logic that keeps the pipeline geometrically honest (Pairwise Intersect). Original illustration by the author.

Read as planning signals, the morphological stack tells a coherent story about each cell. The two density metrics describe what has been committed to construction: Building Surface Fraction (BSF) is the share of the hectare given to footprint, the irreversible decision to

convert open ground into built mass; Impervious Surface Fraction (ISF) is the share sealed against infiltration in any form, footprints plus roads, driveways, paved courtyards, sealed industrial slabs. The two together describe not merely density but commitment: how much of the hectare has been removed from the moisture cycle that sustains the fringe's evaporative buffer. A cell with high ISF and low BSF is the speculative-development signature, sealed without yet being built, the most thermally hostile combination the fringe produces.

The fragmentation metrics describe the structure of what remains. Number of Patches (NP) counts the breaks in continuity: how many separate vegetated pieces survive in a cell, regardless of total area; in an olive-grove cell, a high number signals that a once-continuous canopy has been cut by sealed roads, villa parcels, or abandonment into pieces too small to function climatically together. Largest Patch Index (LPI) asks whether any of those remaining pieces is still big enough to generate its own microclimate, whether the cell retains a dominant green core or has been reduced to a constellation of fragments. Euclidean Nearest Neighbour (ENN) measures the distance between surviving pieces: high values mean the fragments are spatially isolated to the point where the biological corridor function, moisture exchange, thermal continuity are broken between them. Edge Density measures the perimeter exposed to surrounding heat per unit area: a high edge density signals a landscape in which almost every point of vegetation is within radiative distance of a hot bare surface, preventing the development of a stable internal microclimate. Together, these four metrics are a reading of the landscape's structural resilience and its capacity to continue buffering heat under the compounding pressures of sprawl, abandonment, and pathogen-driven canopy collapse.

Wall Density carries the most thesis-specific signal: the length of dry-stone wall per hectare. The Muretti a secco are not a heritage variable; as Chapter 2 argued, they are a calibrated vernacular climate infrastructure — windbreak, moisture-retainer, biological corridor, and shadow-projector, performing simultaneously functions that no sealed boundary can replicate. Their density at the cell scale is the most direct registration of Stone as a functioning ecological identity rather than an inherited landscape memory. Because walls are difficult to detect reliably by automated methods alone and are easily confused with field tracks, shadows, or crop rows, this layer is grounded against a hand-verified dataset built by direct inspection and street-view confirmation, the empirical floor beneath every claim the index makes about Stone.

The uniform geometry of the grid produces two methodological economies worth naming. First, in landscape ecology, fragmentation is conventionally reported as Patch Density, patches per unit area, precisely because patches must be compared across regions of differing extent, but when every analytical unit is identical in area, dividing by a constant area changes nothing in the ranking or relative values. The thesis therefore uses Number of Patches directly, without the redundant per-area normalisation, avoiding arithmetic that would add complexity without adding information. Second: a pairwise-intersection

operation splits each building footprint, each land-cover polygon, and each wall segment at the cell boundary, assigning to every cell only the area, perimeter, and count that physically fall within it, so that a building straddling two cells contributes to both in exact proportion, and no morphology is counted twice or lost at a seam.

The deepest structural decision of the methodology lives in this grid, and it is the decision to build two fishnets rather than one. The geometry is shared — the same grid cells, the same unique cell key on every cell, but the content is split along the axis of time. The first fishnet, the Master Profile, holds the cell's identity: its building and impervious surface fractions, its fragmentation stack, its wall density, its ecological composition, its land use, and the composite scores derived from them, eighty-two fields describing what each hectare of the fringe morphologically and ecologically is. The second fishnet, the Thermal Time-Series, holds the cell's behaviour: more than six hundred fields recording how each hectare acts thermally across twelve satellite scenes spanning four years and three seasons. The two are joined by the unique cell key, the single identifier that runs through both.

This separation is not a storage convenience; it is the argument made structurally. Morphology is slow; a wall, a building, an olive grove change over years or decades. Temperature is fast; it inverts within a single season. A cell's identity is comparatively stable; its thermal state is volatile. Holding the two in separate but joinable fishnets allows the thesis to pose its central question not as an assumption but as an operation: Does the slow identity predict the fast behaviour? Whether and how it does, and what the structure of that prediction reveals about the buffer's seasonal performance, is the empirical work of Chapter 7.

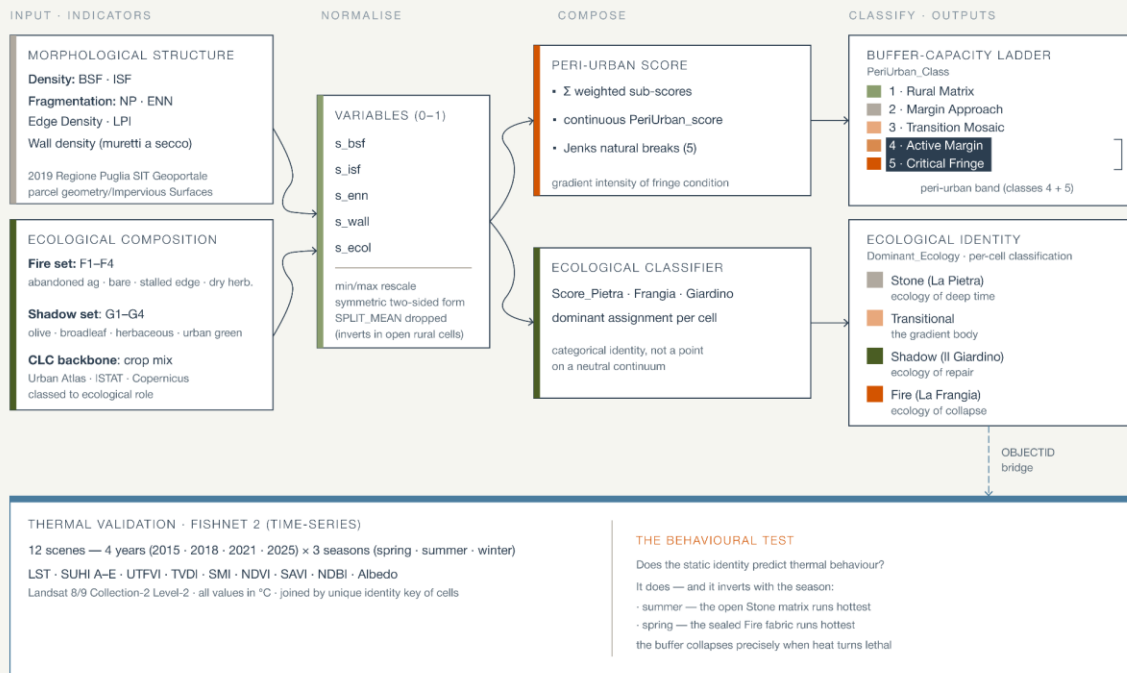
4.4 The Analytical Framework: From Indicators to Identity and Gradient

The RUTZ Index is not a single number pressed out of the data. It is a relational structure — a disciplined path from raw indicators, through normalised variables, to two parallel composite readings that together describe each cell. Figure 4.4 sets out that path in full; this section decodes it because the architecture of the framework is the methodological contribution, and it must be legible before Chapter 9 calibrates and tests it.

Figure 4.3 The RUTZ Analytical Framework

The RUTZ Analytical Framework

From raw indicators to buffer-capacity classification and ecological identity — tested against a multi-season thermal record.



Note. The framework moves left to right: indicators → normalised variables → two parallel composites (buffer-capacity gradient and ecological identity) → outputs, validated against the multi-season thermal record via the unique cell key. Original illustration by the author.

The framework begins with two families of indicators, each chosen for what it tells the planner about a cell rather than for what it tells a sensor operator about a pixel. The morphological family reads built structure: the two density metrics describe how much of the hectare has been committed and sealed; the fragmentation stack describes how what remains is configured; the wall density measures the vernacular climate infrastructure that no standard density metric registers. The ecological family reads land cover and its condition: composition flags decompose each cell into the components of Fire (abandoned agricultural land, thermally exposed bare soil karst, stalled urban edge, dry herbaceous abandonment) and Shadow (active olive grove, broadleaved forest, functional herbaceous mosaic, urban green), together with the Corine Land Cover backbone and the functional crop mix that were cross-validated and identified. These are not yet scores. They are the measured raw material of the fringe's condition.

Table 4.1 Phase 1–3 Baseline Extraction & Cross-Validation Framework

Phase	Primary source	Core operation	Output
Phase 1	Urban Atlas 2021 polygons	Select by code → Export → Clip → Cross-validate	Baselines A, B, C, D, E for Surface Urban Heat Island
Phase 2	Crop Type 2023 raster (10m)	Reclassify → 8 thematic masks	Dead croplands, confirmed olive groves, crops/active agricultural lands
Phase 3	Copernicus Ploughing Indicator + CropType Dataset	Raster Calculator sum → threshold ≥ 2 → spatial constraint	Inactive agricultural signal for The Fire ecology; Functional vegetative spaces (182 polygons, 705.47 ha); Fire ecology composite(247 polygons, 780.64 ha)
Phase 4	Both fishnets + thermal scenes	Zonal Statistics × 216 tables → normalize → composite	Peri-Urban Score (5 classes); Dominant Ecology (4 classes)

Note. 'Phase 1–3 baseline extraction and cross-validation framework. The pipeline fuses Urban Atlas 2021 vector polygons (Phase 1), Copernicus Crop Type 2023 raster masks (Phase 2), and a multi-source abandonment confidence raster (Phase 3) to produce the definitive ecology vector layers that feed all downstream RUTZ analyses. (For full Phase 1–3 cross-validation details, see Table B.1, Appendix A.)

The operational detail of each step, source datasets, ArcGIS tool sequences, output feature class names, polygon counts, and area totals are documented in full in Table A.1, Appendix A. The second move is normalization. Each indicator family is reduced to a set of normalised sub-scores; five variables, each rescaled to a common zero-to-one range so that a wall density measured in metres per hectare and an impervious fraction measured as a proportion can enter the same composite without one drowning the other. The rescaling uses a symmetric, two-sided form: an earlier asymmetric formulation systematically inflated the scores of open rural cells, reading their very emptiness as if it were a peri-urban signal, and the symmetric form removes that distortion. A second fragmentation variable, the splitting index averaged across the cell, was computed and then deliberately dropped from the composite, because in open rural cells it inverted the fragmentation signal, assigning low fragmentation values to precisely the continuous agricultural matrix that the metric was meant to read as intact. Surfacing and excluding it is the kind of follow-the-friction decision that the integrity of a composite instrument depends on.

From the normalised variables, the framework forks into two composites, and the fork is the conceptual heart of the design. The first track sums the weighted sub-scores into a single continuous peri-urban score and then classifies that score into five bands using Jenks natural-breaks classification. Jenks is chosen deliberately over equal-interval or quantile

classing: the score distribution is strongly right-skewed, most of the territory sits low on the peri-urban scale, with a thin tail of intensely transitional cells and natural-breaks classification respects the data's own clustering, drawing its class boundaries where the gradient actually steps rather than where an arbitrary arithmetic would place them. The five resulting bands form a buffer-capacity ladder: Rural Matrix, Margin Approach, Transition Mosaic, Active Margin, and Critical Fringe. The operational peri-urban band, the cells where the buffer logic is genuinely in play and in action, is the union of the two highest classes, Active Margin and Critical Fringe; the acute core of that band, the Critical Fringe alone, is the cells where the transition is most violent.

Table 4.2 Peri-Urban Composite Score — Five Sub-Scores, Normalization & Jenks Classification

Sub-score	Source field(s)	Normalization logic	Planning interpretation
s_bsf	BSF_Value (Building Surface Fraction)	Symmetric two-sided normalization. Higher BSF → higher score. Built density is the primary morphological peri-urban signal.	Higher score = more built coverage per hectare
s_isf	ISF (mean Impervious Surface Fraction)	Symmetric two-sided. Higher ISF → higher score. Sealing beyond building footprint (roads, driveways, sealed yards) is a peri-urban morphological signature.	Higher score = more sealed, less moisture-permeable
s_enn	ENN_Mean (Euclidean Nearest-Neighbor mean, patches)	Symmetric two-sided. Higher isolation distance → higher score. A fragmented landscape of isolated patches is the ecological correlate of peri-urban fragmentation.	Higher score = more isolated patch structure
s_wall	IntraCell Wall Density (m/ha) + Neighbor Wall Density	Symmetric two-sided. Higher wall density → higher score. Vernacular dry-stone wall network is uniquely densified in the Stone karst matrix at the peri-urban interface.	Higher score = richer muretti a secco network
s_ecol	Ecology composition ratio (F-class % vs G-class %)	Symmetric two-sided. Higher Fire-class share (F1–F4 fraction in cell) → higher score; higher Shadow-class share (G1–G4) → lower score. The ecology sub-score implicitly encodes the Phase 3 cross-validation evidence.	Higher score = more abandonment/conflict; lower = more buffer function

Note. 'Composite peri-urban score: five normalized sub-score inputs, normalization logic, and Jenks natural-breaks classification into five ordinal transition-intensity bands. The two-sided symmetric normalization ensures that deviations in both directions from the median are treated consistently. Source field names as recorded in Fishnet Master Profile;

The second track does not grade intensity; it assigns identity. From a parallel scoring of each cell's affinity to the three ecologies, each cell receives a single dominant ecological classification: Stone (La Pietra), Shadow (Il Giardino), Fire (La Frangia), or Transitional. This is a categorical reading, not a continuous one, and that is the point. The Transitional class is

left unnamed because it is the gradient body itself, the vast in-between within which Stone, Shadow, and Fire appear as the legible, conflicted poles.

Table 4.3 Dominant Ecology Assignment — 7-Metric Provisional Scoring Criteria

Metric #	Indicator	Directional weighting by ecology	Ecological rationale
1	BSF_Value (Building Surface Fraction)	Stone: inverse (low BSF → higher Stone score) Fire: proportional (high BSF → higher Fire score) Shadow: low contribution	Distinguishes open karst (Stone) from built fringe (Fire)
2	ISF (Impervious Surface Fraction)	Stone: inverse (low ISF → higher Stone score) Fire: proportional (high ISF → higher Fire score) Shadow: low contribution	Primary built-vs-open discriminator
3	NP (Number of Patches)	Fire: proportional (high NP = fragmented fringe condition) Shadow: inverse (low NP = consolidated canopy) Stone: very low NP (open matrix has no discrete patches to count)	Fragmentation is the morphological fingerprint of Fire
4	ENN_Mean (Euclidean Nearest-Neighbor)	Fire: proportional (high isolation → higher Fire) Shadow: inverse (low isolation → consolidated) Stone: near-zero (no patches to isolate)	Isolation measures ecological network disintegration
5	Edge Density (m/ha)	Fire: proportional (high edge → higher Fire) Shadow: inverse (low edge = consolidated interior) Stone: very low (open matrix has minimal edge)	Edge density is the boundary-exposure proxy
6	IntraCell + Neighbor Wall Density (m/ha)	Stone: proportional (high wall density → higher Stone) Fire: low contribution Shadow: low contribution	The single most Stone-specific indicator; author-built dataset
7	Ecology composition % (F-class vs G-class from Phase 3 layers)	Fire: proportional (high F1–F4 % → higher Fire score) Shadow: proportional (high G1–G4 % → higher Shadow score) Stone: residual (low F and G → defaults toward Stone)	Phase 3 cross-validated abandonment/canopy evidence encoded directly

Note. Seven indicator metrics and their directional weighting by ecology, and the minimum-evidence assignment floor (score ≥ 5 required). Provisional 7-metric run results: Stone 4,306 cells (49.9%); Transitional 3,635 (42.1%); Shadow 465 (5.4%); Fire 219 (2.5%). A Hidden Fire ecology diagnostic identifies 1,464 additional cells carrying F1/F4 abandonment flags but classified as Stone or Transitional by morphology alone. Source: data extraction from Fishnet Master Profile; Phase 3 ecology composition fields; author-built dry-stone wall dataset.¹

¹ Two additional metrics — mean summer Land Surface Temperature and mean summer NDVI, were tested as scoring criteria during classification development and are retained in the FISHNET Master Profile as the 9-metric 'Dominant Ecology (Full)' field (Stone *n* = 2,901; Shadow *n* = 692; Fire *n* = 25; Transitional *n* = 5,007). They are excluded from the provisional scoring for two reasons. First, their inclusion would violate the no-circularity principle that governs the RUTZ validation architecture (§9.3): LST and NDVI both derive from the Landsat thermal and spectral record against which the ecology classification is independently tested, and their

Two outputs from one set of variables. The buffer-capacity ladder answers how peri-urban a cell is; the ecological identity answers which ecology it belongs to. A cell deep in the Critical Fringe may be Fire, but it may equally be Stone, the exposed karst matrix whose summer thermal behaviour, Chapter 7 will read, is far from what the name suggests. The thesis needs both axes because neither alone describes the fringe: intensity without identity cannot distinguish a sealed villa block from a baking open field at the same peri-urban score, and identity without intensity cannot say how far into crisis a given ecology has travelled. The RUTZ Index, properly understood, is this paired reading.

Crucially, the thermal record does not enter the construction of either composite. The identity and the gradient are derived entirely from morphology and ecology; the multi-season thermal time-series enters only afterward, as an independent validation layer. This sequencing is a deliberate guard against circularity. By holding the thermal data out of the construction and bringing it in only as a test, the thesis earns the right to treat the thermal separation of the ecologies as a genuine result.

4.5 Triangulation and Validation: Trusting No Single Instrument

A composite index is only as trustworthy as its willingness to distrust its own components. The validation strategy of this thesis is built on triangulation across three independent axes, source, index, and time, and on a fourth, decisive test: whether a classification built without temperature can predict temperature.

The first axis is source triangulation: confrontation of remote inference with ground truth. The wall-density layer, the most thesis-specific and most easily confounded signal, is grounded against a hand-verified dataset built by direct inspection and street-view confirmation. This is the empirical floor beneath every claim the index makes about Stone as a functioning ecological identity.

The second axis is index triangulation: the principle that no single environmental indicator is trusted alone. Read as planning signals, three vegetation indicators together describe whether a cell carries a functioning canopy (the greenness index), whether that canopy is real or a soil-brightness artefact (the soil-adjusted index), and whether what is there is functioning or terminal, a tree with leaves but a blocked vascular system, the early-stage low evaporative signal (the moisture index). A cell is read as functioning green infrastructure only where all three agree; where they diverge, the divergence is diagnostic. Bare-soil indicators identify the spectral signature of exposed mineral surfaces, the share of a cell that has been stripped of vegetation but not yet sealed, the speculative-abandonment

presence inside the scoring criteria would render that test self-referential. Second, the tightened classification threshold reduced the Fire ecology to 25 cells — an analytically unviable population for the per-ecology thermal statistics reported in Chapter 7. The 7-metric provisional classification (Stone $n = 4,306$; Shadow $n = 465$; Fire $n = 219$; Transitional $n = 3,635$) is the operative classification throughout the thesis.

signature that is one of Fire ecology's most thermally hostile conditions. Soil-moisture indicators, derived from the thermal range of the local population of cells, read the inverse: which cells still retain the evaporative capacity that the dry-summer climate progressively strips away. The same multi-indicator logic governs the thermal stack, where five distinct thermal formulations are computed in parallel so that no single artefact can masquerade as a finding.

The third axis is temporal triangulation: twelve scenes across four years and three seasons, catching the fringe as a process rather than a state. Within this multi-season design, a weak and initially troubling correlation appeared: in high summer, surface temperature and the basic vegetation index correlate only weakly and negatively, far below temperate-climate expectations. This is not a pipeline error. It is the spectral signature of the Mediterranean dry summer itself, seasonal senescence in which Salento's vegetation browns under the Csa drought, so that greenness ceases to track cooling. Read as a finding rather than a fault, it becomes a direct justification for the multi-index, multi-season architecture: in this climate, a single vegetation index in a single summer scene is precisely the instrument one must not rely on alone.

The fourth validation is the behavioural test, which the two-fishnet architecture makes possible. The ecological classification is derived entirely from morphology and ecology, with no thermal input. If the classes are real, if Stone, Shadow, and Fire ecologies of the territory are genuine ecological logics rather than statistical noise, they should separate coherently in the thermal data from which they were never built. Whether and how they do, and what the structure of that separation reveals about the buffer's seasonal behaviour, is the empirical argument of Chapter 7. A classification built blind to temperature, reproducing a coherent, season-dependent thermal structure, would be the strongest validation the design can offer.

Underwriting all four axes is a foundational data-integrity safeguard: every spectral and thermal input was verified to be a Collection-2 Level-2 surface-reflectance product before any index was computed. Triangulation guards against false conclusions; provenance verification guards against false inputs.

4.6 Ethical Considerations and Source Authority

A morphological study of a fringe has no human subjects to consent, no interviews to anonymise, no clinical data to protect. Its ethics lie elsewhere, in the provenance of its sources, in the responsibility for its claims, and in the act of representation itself.

The data foundation is open, public, and attributable. The morphological baseline is the Regione Puglia high-resolution orthophoto (Geoportale Puglia); the administrative geometry and demographic structure derive from the Istituto Nazionale di Statistica; the

land-cover backbone and urban-fabric classifications come from the Copernicus Urban Atlas and the wider Copernicus Land Monitoring Service; the spectral and thermal record is built from USGS Landsat 8/9 Collection-2 Level-2 Science Products. Every layer in the RUTZ Index can be traced to a public authority and re-acquired by any researcher, and this open provenance is what makes the instrument's central promise, transferability to comparable Mediterranean spaces, more than rhetorical.

All spatial layers are co-registered to a single projection, the Universal Transverse Mercator system, Zone 34 North (UTM Zone 34N), chosen because it minimises linear distortion across the Salento peninsula and gives every cell its measurement in true meters. Every distance, every area, every density reported in this thesis is comparable to every other without latent reprojection error, and any researcher reproducing the pipeline at a comparable Mediterranean fringe will find UTM Zone 34N still appropriate from southern Albania to the Ionian coast.

The representational ethic is quieter and more demanding. To grid a lived territory into cells and grade them from Rural Matrix to Critical Fringe is to risk reducing an inhabited landscape to a risk surface. The critical urban geography reading that runs alongside the quantitative analysis is the ethical answer: it insists that a Fire cell is not merely a high impervious fraction but a record of speculative abandonment with consequences for the bodies nearby; that the elderly cohort the Heat Risk Index will flag in Chapter 8 are not a demographic layer but the population most likely to die in the next heatwave the fringe fails to buffer. The thesis maps the fringe as inhabited conflict, not as empty data.

Finally, this thesis has been developed with computational and analytical assistance, but the author bears full and final responsibility for verifying every datum, every citation, and every figure against its source before submission. Reproducibility, the full pipeline documented at UTM Zone 34N, every processing step recoverable, is the last ethical commitment of the methodology: an instrument offered openly to be tested, transferred, and where it is wrong, corrected.

The methodology is now constituted. The next chapter executes it.

Chapter 5

CHAPTER 5: The Spatial Data Pipeline

If Chapter 4 was the constitution of the method, Chapter 5 is its engine room. Where the preceding chapter argued why the research was designed as it was — why a 100-meter fishnet, why a gradient logic rather than a municipal comparison, why a composite index rather than a single metric, this chapter documents how that design was executed, operation by operation, with sufficient precision that a competent analyst could reconstruct the pipeline from these pages alone. Reproducibility is not a bureaucratic virtue here; it is the condition under which the RUTZ Index can claim to be an instrument rather than an assertion.

The chapter is organized as the data itself flows: from acquisition (section 5.1), through pre-processing and projection (section 5.2), into the three families of derived variables morphological (section 5.3), spectral and ecological (section 5.4), and deep-learning-derived (section 5.5) and finally through the automation layer (section 5.6) and the fragmentation analysis (section 5.7) that bind the whole into a single attribute table. At several points, the pipeline encountered genuine friction: a data-collection level mismatch, a geometric operation that silently corrupted area calculations, a fragmentation metric that inverted its own signal. These are not hidden. Following the principle of follow-the-friction rigor that has governed the entire project, each is surfaced here as a methodological finding, because the resolution of a real problem is more instructive than the smooth recitation of a procedure that never failed.

Three terminological notes orient the reader. First, the unit of observation throughout is the one-hectare fishnet cell; 8,625 of them tile the study area. Second, the three ecological typologies that the pipeline ultimately assigns to each cell are named, following the supervisor's guidance, in materialistic English: the Stone ecology (the sealed, impervious karst-urban matrix), the Fire ecology (the abandoned, thermally exposed, conflictual peri-urban fringe), and the Shadow/Canopy ecology (the managed vegetated grove and ecological transition buffer), with a fourth Transitional class for cells that resolve to none of the three with sufficient dominance. The original Italian field values are preserved internally in the geodatabase for cross-referencing. Third, all temperature outputs are expressed in degrees Celsius; no downstream conversion is required anywhere in the analysis.

5.1 Data Acquisition: Source Quality and Temporal Alignment

The pipeline is organized into four sequential phases. Phase 1 extracts reference baseline polygons from the Urban Atlas 2021 (§5.1–5.2); Phase 2 reclassifies the Copernicus Crop Type 2023 raster into functional ecological masks (§5.4); Phase 3 fuses those vector and raster layers into a cross-validated composite for each ecology (§5.4, ecology composition); Phase 4 computes the full spectral and thermal index stack across twelve

Landsat scenes, executes the zonal statistics summarization, and populates the master fishnet (sections 5.4–5.7). Phases 1–3 produce the ecological anatomy of the territory; Phase 4 records its thermal behaviour. A territory as morphologically layered as the Salento fringe cannot be read through a single sensor or a single dataset. The pipeline therefore triangulates across three classes of source: remotely sensed imagery for the thermal and spectral signal; authoritative cartographic and land-cover products for the ecological and administrative substrate; and vector datasets, some institutional, one author-built for the morphological geometry. The discipline of acquisition lies not in collecting as much data as possible but in matching each source to the single role it can authoritatively perform, and refusing to ask it to perform any other.

The thermal and spectral backbone of the analysis is the Landsat 8/9 archive, acquired exclusively as Collection-2 Level-2 Science Products. This decision is consequential and is defended in detail in section 5.2; here it is enough to state that the Level-2 product delivers atmospherically corrected surface reflectance and an emissivity-corrected surface temperature, rather than raw at-sensor digital numbers, and that building an index pipeline on the wrong product level produces physically impossible results. Twelve scenes were assembled, structured as a four-by-three temporal matrix: four reference years (2015, 2018, 2021, and 2025) crossed with three seasonal windows, yielding a time series capable of distinguishing a durable landscape signal from ephemeral seasonal noise. Scene selection within each window prioritized cloud-free coverage of the study area, with the QA_PIXEL quality band used to confirm that the fishnet extent was unobstructed.

The ecological substrate is anchored by CLCbackbone plus 2023, the latest authentic raster land-cover dataset produced under the Copernicus Land Monitoring Service. Unlike the vector-generalized Urban Atlas, which classifies territory into coarse functional polygons, the CLCbackbone resolves land cover into a fine-grained raster of eight physiognomic classes (woody broadleaved evergreen, woody broadleaved deciduous, woody needle-leaved, low-growing woody, permanent herbaceous, periodically herbaceous, non- and sparsely-vegetated, and sealed). This granularity is precisely what the Fire and Shadow/Canopy ecologies require: the difference between a periodically-herbaceous abandoned parcel and a permanently-herbaceous functional mosaic is invisible to Urban Atlas but legible to the CLCbackbone, and that difference is exactly the boundary between thermal liability and thermal buffer. The canopy layer is reinforced by the Copernicus High-Resolution Layer Tree Cover Density 2023 at 10-meter resolution, and the detection of inactive agricultural land, the spectral signature of the Fire ecology, draws on the Copernicus Ploughing Indicator.

Dataset	Source / Provider	Role in the Pipeline
Landsat 8/9 Collection-2 Level-2	USGS / EROS Center (2020)	Thermal (LST) and surface-reflectance spectral indices across 12 scenes (4 years x 3 seasons).

Dataset	Source / Provider	Role in the Pipeline
CLCbackbone 2023 (raster land cover)	Copernicus Land Monitoring Service	Fine-grained, authentic land-cover backbone; basis for ecological class composition.
Tree Cover Density 2023 (10 m)	Copernicus CLMS (HRL)	Primary canopy reference layer for the Shadow/Canopy ecology.
Ploughing Indicator	Copernicus CLMS	Detection of inactive / abandoned agricultural parcels (Fire ecology).
Ortofoto 2019 AGEA	SIT Puglia / Regione Puglia (WMS)	Reserved exclusively for deep-learning canopy detection.
Building footprints	OpenStreetMap via Geofabrik	Built-up geometry for BSF and morphological metrics.
Dry-stone wall network (muretti a secco)	Author-built; cross-validated vs. Regione Puglia data	Wall-density metrics; ecological-thermal connectivity variable.
Urban Atlas 2012 / 2021	Copernicus CLMS	Reference geometries for SUHI computation; invisibility diagnostic.
ISTAT census sections 2024	ISTAT via Esri ArcGIS Living Atlas	Demographic substrate (reserved for Chapter 8 / HRI).

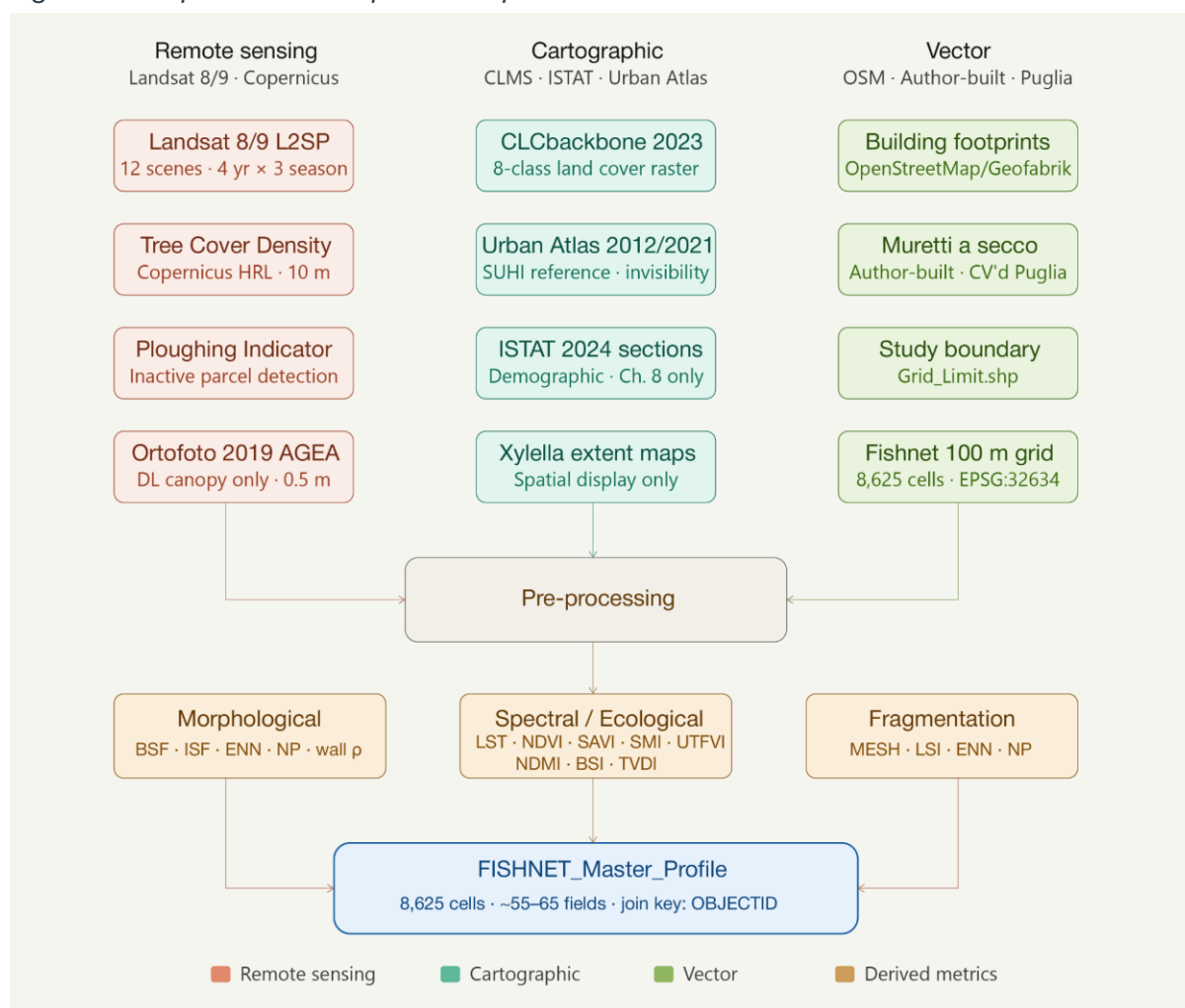
Two acquisition decisions correct common shortcuts and deserve an explicit statement. First, building footprints were not extracted from the orthophoto. They were acquired as vector geometry from OpenStreetMap via the Geofabrik distribution, a source whose topological cleanliness and attribute consistency far exceed what photo-interpretation or automated footprint extraction could deliver at this scale. Second, and correspondingly, the orthophoto the Ortofoto 2019 AGEA color orthophoto served through the SIT Puglia infrastructure was reserved exclusively for deep-learning canopy detection (section 5.5), the one task for which its 0.5-meter resolution is indispensable and for which no superior alternative exists. Conflating these two roles using the orthophoto for footprints, or OSM for canopy would have degraded both. The orthophoto is cited throughout as: Source: SIT Puglia / Ortofoto 2019 AGEA.

The dry-stone wall network the muretti a secco that subdivides the Salento matrix and that the supervisor specifically identified as a climate-relevant variable is unique to this research. No institutional vector dataset of the Salento walls exists at the required resolution. The network was therefore built by hand: manually digitized from high-resolution imagery and Google Street View verification, then enriched and cross-validated against the available Regione Puglia spatial data. The resulting layer feeds the Neighbor Wall Density and IntraCell Wall Density metrics (expressed in meters per hectare) that enter the composite peri-urban score. This is, to the author's knowledge, the first quantitative wall-density characterization of the Lecce fringe at the hectare scale.

The administrative and land-cover framework is completed by the Urban Atlas reference geometries (2012 and 2021), which serve as the fixed comparison surfaces for the SUHI

computation and as the diagnostic baseline for the fringe's documented invisibility to standard classification, and by the ISTAT 2024 census sections accessed through the ArcGIS Living Atlas, which provide the demographic substrate. The *Xylella fastidiosa* pathogen-front maps published by the regional authority were used in earlier chapters strictly to delineate and display the affected areas as spatial reference; they were not used to interpret any NDVI signal within those cells, and no spectral inference is drawn from them. The ISTAT demographic layer is held in reserve: it is mobilized only in Chapter 8, where the Heat Risk Index operates at the municipal scale. Chapters 5 through 7 remain, by design, on the continuous gradient logic of the fishnet, with no municipal aggregation.

Figure 5.1 Spatial Data Acquisition Pipeline: Three Source Families and Their Authorized Roles



Note. The three source families include remote sensing, cartographic datasets, and vector geometry; each carry a single authorized role in the pipeline before converging through the pre-processing stage into the FISHNET Master Profile. attribute table. Source: author's elaboration.

5.2 Pre-processing and Projection

Every raster and vector layer in the analysis converges on a single coordinate reference frame: EPSG:32634 (WGS 84 / UTM Zone 34N), the projected system appropriate to the longitude of the Salento peninsula and the one that preserves area and distance with the

fidelity that morphological and thermal metrics demand. All processing is consolidated within a single file geodatabase, Lecce Prime geodatabase, whose feature datasets enforce the common projection and whose internal organization mirrors the logical stages of the pipeline. A geodatabase is not merely a container; it is a discipline, ensuring that no layer enters an analysis in a foreign coordinate system and silently distorts the result.

The single most consequential pre-processing decision concerns the radiometric interpretation of the Landsat data. Collection-2 Level-2 products store their physical values as scaled integers, and the scaling differs fundamentally from the Collection-1 convention that much of the older literature assumes. Surface reflectance is recovered by applying a multiplicative factor and an additive offset to the stored digital number; surface temperature is recovered by a separate pair of constants. The rescaling that governs the entire spectral stack is:

$$\text{Surface Reflectance} = (\text{DN} \times 0.0000275) - 0.2$$

and the surface-temperature recovery, converting the Kelvin product directly to Celsius, is:

$$\text{LST (}^{\circ}\text{C)} = (\text{DN} \times 0.00341802) + 149.0 - 273.15$$

These constants are not arbitrary; they are the published scaling factors for Collection-2 Level-2 Science Products (USGS / EROS Center, 2020). To decode the second expression for the urban designer: the stored integer is first stretched back into Kelvin by the gentle multiplicative factor and the large additive offset, and then translated into the everyday Celsius scale by subtracting the freezing point of water. The output is a per-pixel map of the actual radiating temperature of the ground surface; the asphalt, the limestone, the olive canopy at the moment of overpass. Once this rescale is in place, every downstream index inherits physically meaningful inputs, and the denominator guards added to each band-math expression prevent division-by-zero artifacts where reflectance values collapse toward zero over water or deep shadow.

The full set of spectral indices was re-derived after this correction, with each output clamped to its theoretically valid range, NDVI, NDBI, and NDMI to the interval from minus one to plus one to suppress the physically impossible values that an uncorrected pipeline silently generates. Rasters were aligned to a common 30-meter grid (the native resolution of the Landsat thermal product as delivered), mosaicked where scene boundaries crossed the study area, and clipped to the study boundary.

5.3 Morphological Indices: Reading Built Form on the Grid

Morphology is the first language in which the fringe speaks. Before any thermal or ecological signal is read, each cell is characterized by the quantity and configuration of its built mass, how much of the hectare is occupied by buildings, how much by impervious surface, how the built patches are distributed, and how isolated each is from its neighbors. These metrics are computed in ArcGIS Pro Model Builder from the OpenStreetMap building geometry and

the derived impervious surfaces, and summarized to the fishnet through a sequence of geometric operations whose correctness is less obvious than it appears.

The two primary density measures are the Building Surface Fraction and the Impervious Surface Fraction:

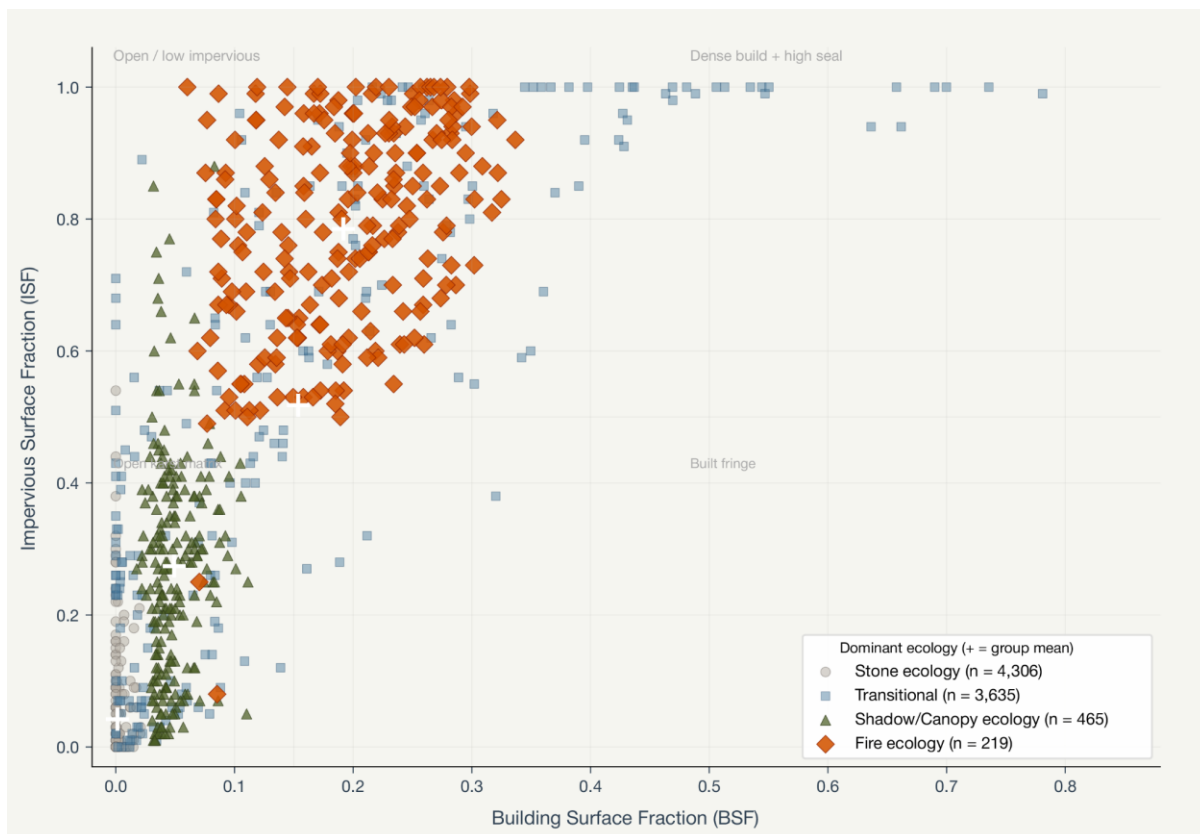
$$\begin{aligned}\text{BSF} &= (\text{building area within cell}) / (\text{cell area}) \\ \text{ISF} &= (\text{impervious area within cell}) / (\text{cell area})\end{aligned}$$

Decoded spatially, BSF measures how thoroughly a hectare has been converted from ground to roof, the degree to which the sky is sealed off from the soil by built mass, while ISF measures the broader sealing of the ground plane by any impervious material, roofs and roads and yards alike. In the thermal logic of the thesis, these two fractions are the morphological antagonists of the buffer: as BSF and ISF rise, the cell's capacity to absorb rainfall, sustain vegetation, and dissipate heat through evapotranspiration falls. The Stone ecology is, in essence, the high-BSF, high-ISF end of this continuum.

The summarization of building geometry to the fishnet exposed the first geometric trap. When building polygons are summarized to cells using a standard Clip, polygons straddling a cell boundary are silently mishandled, and the per-cell area totals drift from their true values. The Pairwise Intersect operation, by contrast, correctly partitions each polygon at the cell boundary and assigns the correct fractional area to each cell it touches. The distinction between Merge (which concatenates features while preserving their individual geometries) and Dissolve (which fuses them into a single geometry, eliminating internal boundaries) compounded the risk: applying the wrong one at the wrong stage either double-counts shared edges or erases the patch structure that the fragmentation analysis later depends upon.

A second, subtler finding concerns fragmentation arithmetic on a uniform grid. Because every fishnet cell is identical in area (one hectare), the Patch Density metric, patches per unit area, and the Number of Patches metric become numerically identical at the cell scale; dividing by a constant area changes nothing. The pipeline therefore uses the Number of Patches directly, avoiding the redundant and potentially misleading PD computation. This equivalence, trivial once stated, is the kind of insight that only emerges from working the arithmetic against real uniform-cell data.

Figure 5.2 - Building Surface Fraction vs. Impervious Surface Fraction by Dominant Ecology



Note. Scatter plot of Building Surface Fraction (BSF) against Impervious Surface Fraction (ISF) for a stratified sample of 769 fishnet cells (up to 220 per ecology; all 219 Fire ecology cells included), coloured by dominant ecology. Cross markers (+) indicate ecology-group means. Fire ecology (mean BSF = 0.19, ISF = 0.79) occupies the high-seal, high-build quadrant the most morphologically dense configuration in the study area, concentrated in the peri-urban fringe. Stone ecology (mean BSF = 0.001, ISF = 0.04) compresses at the origin, confirming its character as an open karst matrix rather than built fabric. Shadow/Canopy ecology clusters in the low-BSF, low-to-moderate ISF zone consistent with managed vegetated groves. Building footprints: OpenStreetMap via Geofabrik. Data: FISHNET Master Profile dataset.

5.4 Spectral and Ecological Indices: The Band-Math Layer

With physically corrected reflectance and temperature in hand, the pipeline derives the family of spectral indices that translate raw radiance into ecological and thermal meaning. Each index is a deliberate ratio or difference of spectral bands, engineered to isolate a particular landscape property, green vitality, surface moisture, bare exposure, built density, thermal stress. The persona of this thesis treats each not as a formula to be recited but as a question the landscape is being asked. The Landsat band assignments used throughout are Blue (B2), Green (B3), Red (B4), Near-Infrared (B5), Shortwave-Infrared-1 (B6), Shortwave-Infrared-2 (B7), and Thermal-Infrared (B10).

Vegetation vitality: NDVI and SAVI

The Normalized Difference Vegetation Index asks how vigorously a surface photosynthesizes, exploiting the steep contrast between a leaf's strong near-infrared reflectance and its strong red absorption:

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red})$$

Healthy canopy returns high values; bare karst and asphalt return values near zero (Rouse et al., 1974; Tucker, 1979). But over the sparsely vegetated Salento fringe, where exposed soil dominates the inter-canopy space, the bare background contaminates the NDVI signal. The Soil-Adjusted Vegetation Index corrects for this by inserting a soil-brightness term L , set here to the standard 0.5 for intermediate cover (Huete, 1988):

$$\text{SAVI} = ((\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red} + L)) \times (1 + L), \quad L = 0.5$$

Where NDVI reads the olive canopy as if it floated against a neutral ground, SAVI reads it against the real, hot, bright limestone soil that surrounds it — and in a landscape defined by the interplay of sparse green and exposed stone, that correction is not cosmetic but structural.

Moisture and bare exposure: NDMI, BSI, and the Soil Moisture Index

The Normalized Difference Moisture Index contrasts near-infrared with shortwave-infrared to sense the water held in vegetation canopies and surface soils (Gao, 1996; Wilson & Sader, 2002):

$$\text{NDMI} = (\text{NIR} - \text{SWIR1}) / (\text{NIR} + \text{SWIR1})$$

The Bare Soil Index inverts the vegetation logic, combining the shortwave-infrared and red against the near-infrared and blue to foreground exposed, unvegetated ground — the spectral fingerprint of the Fire ecology's thermally exposed bare surfaces (Rikimaru et al., 2002):

$$\text{BSI} = ((\text{SWIR1} + \text{Red}) - (\text{NIR} + \text{Blue})) / ((\text{SWIR1} + \text{Red}) + (\text{NIR} + \text{Blue}))$$

The Soil Moisture Index translates the relationship between surface temperature and vegetation into a relative measure of how moist each pixel is, exploiting the geometry of the LST–NDVI feature space, where the hottest pixels at a given vegetation level mark the dry edge and the coolest mark the wet edge (Sandholt et al., 2002; Parida et al., 2008):

$$\text{SMI} = (\text{LST}_{\text{max}} - \text{LST}) / (\text{LST}_{\text{max}} - \text{LST}_{\text{min}})$$

A value of zero locates a pixel on the dry edge, a value of one on the wet edge. A crucial caveat must accompany every use of this index: SMI expresses moisture relatively, within a single scene — it tells us which parts of the fringe are moister than others on a given day, not the absolute volumetric water content of the soil, which would require ground calibration the study does not possess. Read correctly, SMI is a map of comparative thirst across the territory, and in a Mediterranean dry summer the spatial pattern of that thirst is exactly what distinguishes a functioning buffer from a failing one.

Thermal stress: LST, TVDI, and UTFVI

Land Surface Temperature, recovered as described in §5.2, is the thesis's central thermal observable. From it, two interpretive indices are derived. The Temperature-Vegetation Dryness Index situates each pixel within the NDVI–LST triangle to express surface dryness (Sandholt et al., 2002). The Urban Thermal Field Variance Index, the more important of the two for this thesis, measures how far each pixel departs from the mean thermal field of the whole area, converting absolute temperature into a relational statement of thermal comfort (Liu & Zhang, 2011):

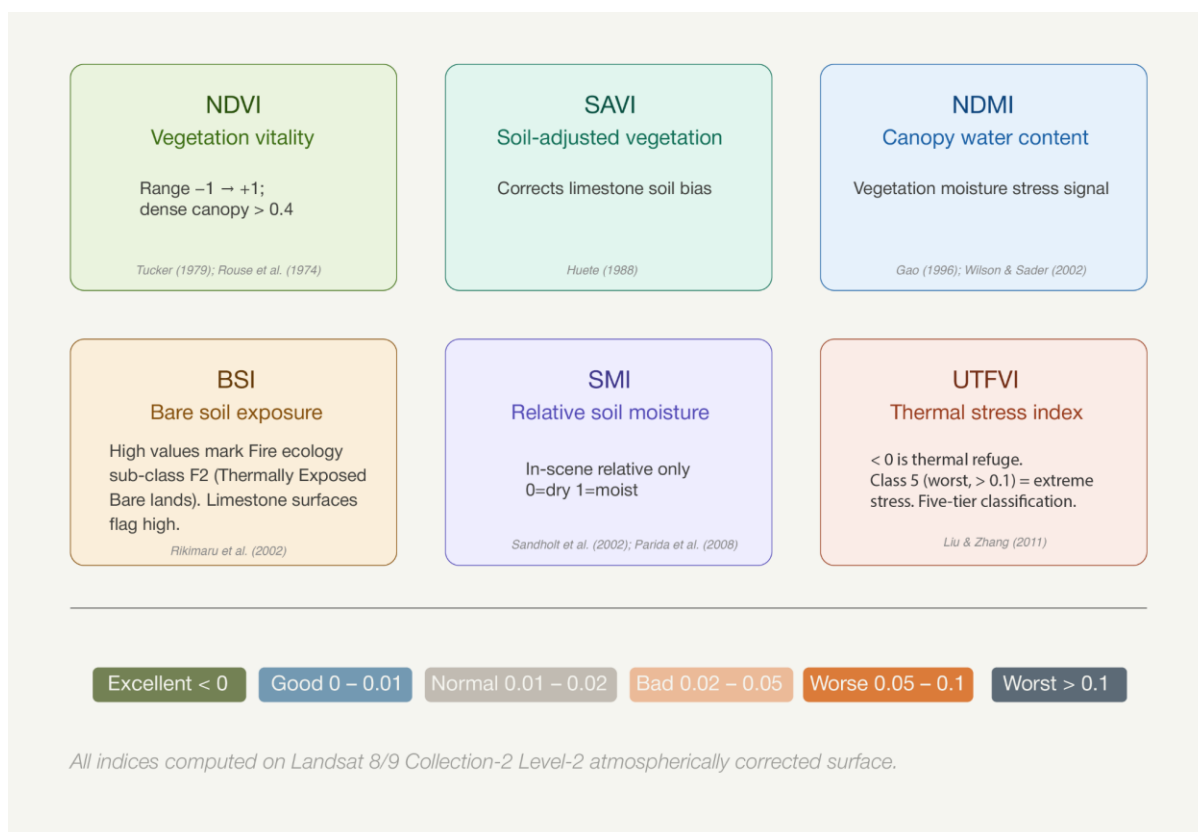
$$\text{UTFVI} = (\text{LST} - \text{LST}_{\text{mean}}) / \text{LST}_{\text{mean}}$$

Decoded for the planner: a negative UTFVI marks a pixel cooler than the territorial average, a thermal refuge, a place that a resident can shelter in extreme heat conditions, while rising positive values mark progressively worse thermal stress, classified in the literature into a six-tier ecological-evaluation scheme from 'excellent' to 'worst.' Applied to the Lecce fringe, UTFVI performs a quietly subversive reading: it identifies where the buffer still holds and where it has failed, and it does so in the relational language a planning audience can act upon, rather than in absolute degrees that mean little without context.

Albedo

Surface albedo — the fraction of incoming shortwave radiation a surface reflects rather than absorbs — is estimated from the corrected reflectance bands using the established narrowband-to-broadband conversion (Liang, 2001). Albedo is the physical hinge of the Pietra Leccese argument developed in Chapter 6: the limestone's relatively high albedo is what allows the historic stone fabric to reflect rather than store the summer sun, and the collapse of albedo across the asphalt and bare-soil surfaces of the degraded fringe is what converts those cells into heat reservoirs.

Figure 5.3 - Spectral Index Reference Panel



Note. The meaningful single-metric maps (LST 2015/2021/2025, SMI, UTFVI) are reserved for their analytical home in section 7.2 – 7.3; this gallery is a methodological reference panel.

Ecology Composition: Phase 1–3 Cross-Validation Pipeline

The ecology composition fields on the Master Profile fishnet are derived from the Phase 1–3 vector layers through Tabulate Intersection rather than Zonal Statistics. The ecology composition fields on the Master Profile fishnet are derived from the Phase 1–3 vector layers through Tabulate Intersection rather than Zonal Statistics, because the underlying data are categorical (polygon-type membership) rather than continuous. For each cell, five Tabulate Intersection operations record the proportional area of each ecology sub-class (F1–F4 for Fire, G1–G4 for Shadow, C1–C3 for Stone, plus the Baseline A rural classes) within the 100-metre boundary. These percentage fields are the `s_ecol` sub-score input to the peri-urban composite and the direct evidence base for the Dominant Ecology assignment (Table 4.3). The UA 32000 herbaceous class required a prior bifurcation step (Phase 3.5): Zonal Statistics MAJORITY was run against four rasters (Herbaceous Cover 2023, Grassland 2023, Ploughing Indicator 2023 reclassification, CROP_NoCropland_2023), and a Python conditional populated a Bifurcation_Class field distinguishing G3_Functional (99 polygons, 405.47 ha, retained in Il Giardino), F4_DryHerbaceousAbandoned (17 polygons, 85.77 ha, reassigned to La Frangia), and Ambiguous_Transitional (116 polygons, 315.58 ha, shown as hatching in the abstractive maps). The refined Il Giardino composite (GRN_Giardino_Functional_2021, 182 polygons, 705.47 ha) replaces the provisional 315-polygon layer for all downstream operations.

The detection of functional collapse in the Fire ecology required a multi-source confidence raster rather than a single spectral index, because no single dataset can see the degraded lands completely. The Urban Atlas captures structural anomalies but is blind to collapse inside stable polygons; the Crop Type raster detects absence of active cropping but combining abandonment with non-agricultural surfaces; the Ploughing Indicator records soil disturbance recency but carries no information for 93.8% of the study area. Only by summing three independent binary evidence streams — (A) the NoCropland mask, (B) the PLI LongFallow class (values 3–5, land not ploughed for three to five years), and (C) the Undecided Perennial class (Crop Type value 3200) — into a single confidence raster does the true spatial extent of abandonment become legible. The resulting FRAN_AbandonmentConfidence_2023 raster scores 0 to 2 per pixel (value 3 was not reached at any location in the study area, because the PLI's 1,908 active cells never coincided simultaneously with NoCropland and Undecided Perennial at the same pixel). Thresholded at ≥ 2 and constrained to agricultural polygon boundaries, the high-confidence abandonment mask identifies 1,268 cells (12.68 ha) of raster-confirmed abandonment evidence — the empirical core of the FRAN_HighConf_Agricultural_2023 layer that appears in the Fire ecology abstractive map.

The transect extraction and a genuine seasonal finding

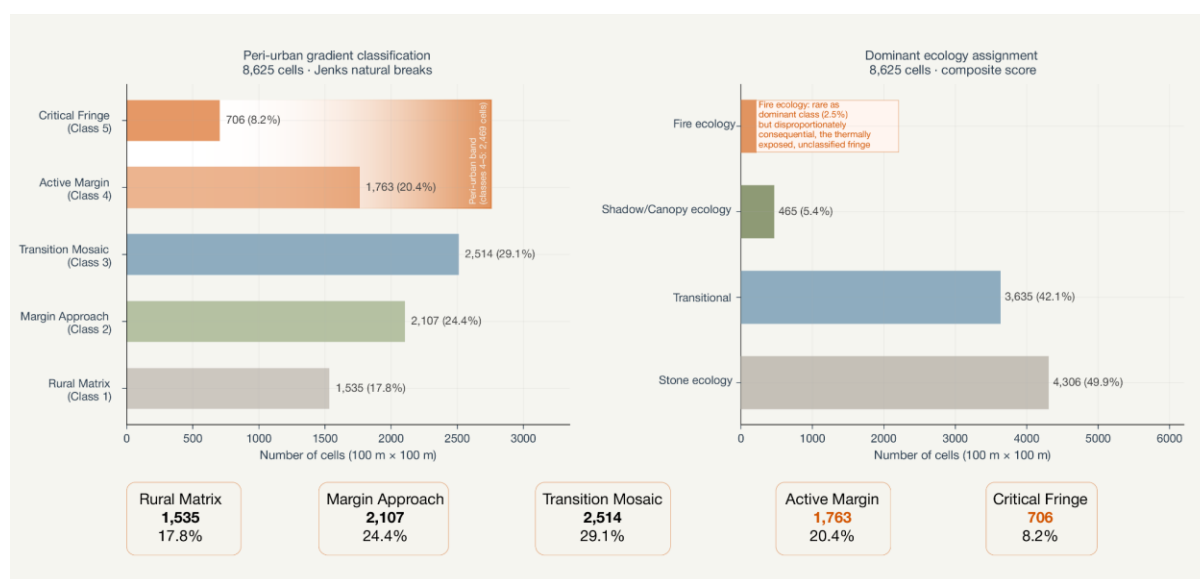
Beyond the cell-level zonal summaries, the thermal indices were extracted along the north–south transect at 30-meter intervals — the native pixel pitch of the Landsat thermal product — running continuously from the historic core to the transect's rural terminus. This fine-grained profile, capturing LST, SMI, and UTFVI at every step, produces a one-dimensional thermal stratigraphy of the gradient that complements the two-dimensional cell maps; it is the empirical spine of the transect masterplan and the cooling-stratigraphy reading developed in Chapter 7. The dual extraction strategy, coarse zonal statistics across all 8,625 cells, larger territorial scale, plus a dense 30-meter interval stack profile along the transect, lets the analysis move fluidly between the territorial pattern and the linear section, enabling the extraction of meaningful thermal patterns, and morphological behaviors.

One result of the spectral analysis deserves to be named not as an error but as a finding. The summer correlation between LST and NDVI across the fringe is weak and negative (approximately -0.342), far from the strong inverse relationship that temperate-climate urban-heat studies report. This is not a pipeline failure; it is a true signature of the Mediterranean dry summer, in which NDVI senescence, the seasonal browning of herbaceous cover under drought stress, decouples the vegetation index from its cooling function. The grass is technically present but physiologically dormant, no longer transpiring, no longer cooling. This decoupling is precisely why a single vegetation index cannot carry the buffer argument alone, and why the multi-index design of the RUTZ framework, pairing

NDVI with SAVI, NDMI, SMI, and the thermal indices, is methodologically necessary rather than merely thorough.

The spectral and land-cover layers feed, finally, the ecological class composition of each cell. The Fire ecology is constituted by four sub-classes — Abandoned Agricultural (F1), Thermally Exposed Bare (F2), Stalled Urban Edge (F3), and Dry Herbaceous Abandoned (F4) — while the Shadow/Canopy ecology is constituted by Active Olive Grove (G1), Broadleaved Forest (G2), Functional Herbaceous Mosaic (G3), and the Urban Green classes (G4, private/public/unknown). The Stone ecology aggregates the sealed and continuous-to-discontinuous urban-fabric classes. Across the full 8,625-cell grid, the Stone ecology is dominant in 4,306 cells (49.9%), the Transitional class in 3,635 (42.1%), the Shadow/Canopy ecology in 465 (5.4%), and the Fire ecology in 219 (2.5%). The rarity of Fire as a dominant ecology across the whole grid is itself instructive: the conflictual fringe is not a large territory, but a thin, concentrated, and disproportionately consequential one — which is exactly why a coarse classification overlooks it and a hectare-scale instrument must be built to find it.

Figure 5.4 - Peri-Urban Gradient Classification and Dominant Ecology Distribution — 8,625 Fishnet Cells



Note. Left panel: distribution of the 8,625 fishnet cells across the five Peri-Urban Classes produced by Jenks natural-break classification of the composite peri-urban score. The peri-urban operational band (Classes 4 and 5 combined Active Margin and Critical Fringe) encompasses 2,469 cells (28.6% of the study area) and constitutes the analytical foundation of the RUTZ Index constructed in Chapter 9. Right panel: distribution by dominant ecology. Fire ecology, though dominant in only 219 cells (2.5% of the grid), marks the thermally conflictual fringe that standard classification systems cannot detect the condition that necessitates a hectare-scale instrument. Source: author's analysis. Data: *Extracted from Fishnet Master Profile dataset*

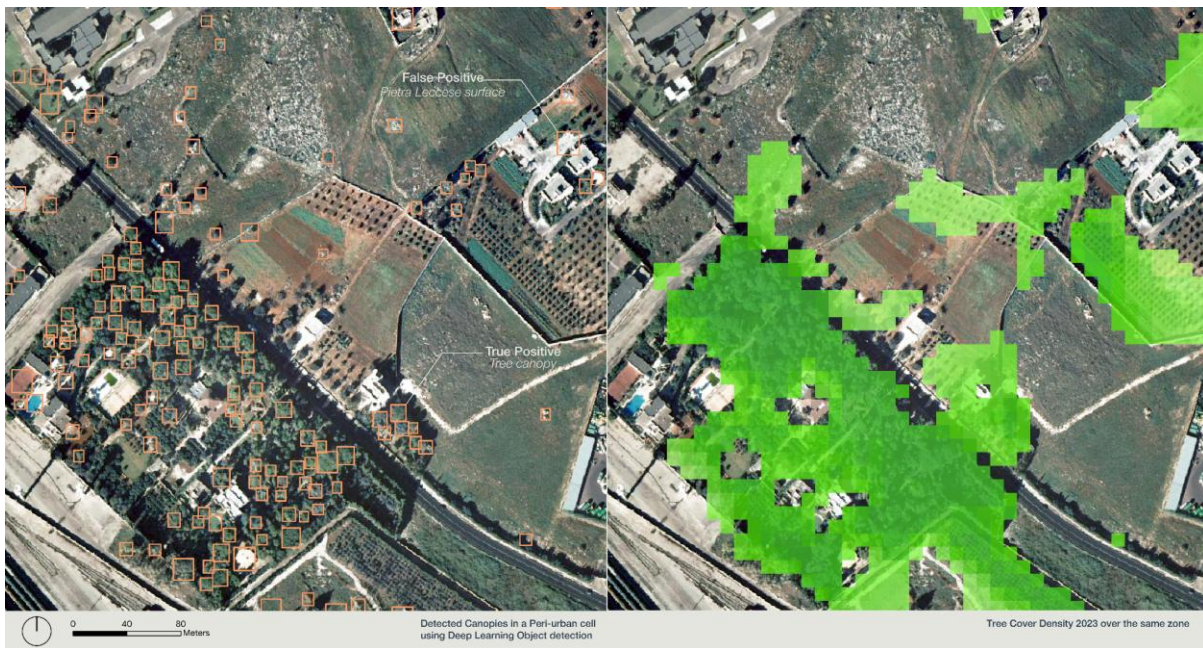
5.5 Deep Learning Integration: Canopy Detection and the Limestone Lesson

The Copernicus Tree Cover Density layer provides a robust regional canopy reference, but at 10-meter resolution it cannot resolve the individual olive trees, isolated grove fragments, and thin tree lines that define the fine grain of the Shadow/Canopy ecology. To recover that detail, the pipeline turned to deep learning, applying ArcGIS Pro's Detect Objects Using Deep Learning tool to the 0.5-meter Ortofoto 2019 AGEA imagery, the single task for which the orthophoto was acquired.

The initial ambition was object-level tree detection and segmentation, delineating each canopy as a discrete instance. This collided with two limits. The first was hardware: the available RTX 3080 GPU, capable as it is, imposed memory ceilings that constrained the tile size and model complexity that could be processed across an 86-square-kilometer extent. The second, and more interesting, limit was spectral-morphological: bare Pietra Leccese surfaces, limestone walls, unpaved courtyards, exposed karst outcrop, reflect across the visible spectrum in a manner the model repeatedly confused with the crowns of olive trees, generating systematic false positives. The very material that gives the Salento its luminosity, and that confers its real albedo-driven cooling, deceived the algorithm that was trying to count its trees.

The resolution was a pivot from instance-level tree detection to pixel-based land-cover classification, in which canopy is identified as a class of pixels rather than as enumerated objects, and the deep-learning output is reconciled against the Copernicus Tree Cover Density reference to suppress the limestone false positives. This pivot sacrificed the elegance of per-tree counts for the robustness of a defensible canopy fraction, a trade the thesis makes consciously and documents as such.

Figure 5.5 Deep Learning Canopy Detection and Limestone False Positives along with Tree Coverage



Note. Detection output of Esri’s pre-trained tree detection model (Detect Objects Using Deep Learning, ArcGIS Pro), applied to the 0.5m Ortofoto AGEA 2019 (left panel), compared against the Copernicus High-Resolution Layer Tree Cover Density 2023 reference at 10m resolution (right panel), over the same 400×400m orthophoto crop in the peri-urban fringe. White outlines indicate detected tree objects; false positives on bare Pietra Leccese surfaces are annotated. The spectral similarity between luminous limestone and grey-green olive canopy in the visible spectrum is the fundamental limitation of object-detection approaches in this geological context, and motivated the adoption of pixel-based TCD-referenced canopy fraction as the operative canopy measure for all subsequent analysis. Source: SIT Puglia / Ortofoto 2019 AGEA; Copernicus CLMS TCD 2023; author’s analysis.

METHODOLOGICAL FINDING: Spectral indices and object-detection models calibrated for temperate or tropical contexts misclassify high-albedo Mediterranean limestone as vegetation. In a Pietra Leccese landscape, bare stone and tree canopy occupy overlapping regions of the visible spectrum; any canopy-detection workflow must include an explicit reconciliation step against an independent reference layer, or it will systematically over-count green where there is only stone.

5.6 Python Automation: Reproducibility at Scale

A pipeline that must be executed twelve times, once per scene, across 8,625 cells and dozens of derived variables cannot be driven by hand without accumulating error. The automation layer is therefore not a convenience but a precondition of trustworthiness. The spatial operations are orchestrated through ArcPy scripting within the Model Builder environment, with fragmentation metrics computed in Python via the pylandstats library rather than the FRAGSTATS desktop application, a choice that keeps the entire fragmentation computation inside a scriptable, reproducible, open-source stack.

The architecture of the automation is itself a finding worth documenting. Rather than a single monolithic model, the pipeline is organized as a family of focused sub-models, one for morphology, one for the spectral stack, one for zonal summarization, and so on,

orchestrated by a master model that the project refers to, with some affection, as the God Model. The master model invokes each sub-model in the correct sequence, passing outputs forward, so that the entire pipeline from raw scene to populated attribute table can be re-run as a single operation. The full set of model diagrams is reproduced in Appendix C; their logic, rather than their pictorial detail, is the methodological contribution.

The zonal summarization stage alone generated 216 Zonal Statistics output tables, one per variable per scene, which were renamed through a scripted batch operation to enforce a consistent, machine-parseable naming convention across the entire set, with every table verified after renaming. This scale of bookkeeping is invisible in the final maps but is precisely what allows the two-fishnet architecture, the static Master Profile and the dynamic Thermal Time-Series — to be joined reliably on the unique cell identifier without silent misalignment.

5.7 Mathematical Morphology: Fragmentation at the Parcel Scale

The final layer of characterization reads not the quantity of built or vegetated surface but its configuration — whether a cell's patches are consolidated or shattered, connected or isolated. Fragmentation is the morphological signature of the fringe condition itself: the deep rural matrix is coarse-grained and continuous, the compact urban core is uniformly sealed, and the Fire ecology in between is finely shattered — abandoned parcels, stalled construction, isolated villas, and surviving grove fragments interleaved at a grain that no coarse classification resolves.

The class-level fragmentation metrics are computed at a 10-meter working resolution through `pylandstats` and summarized to each cell: the Number of Patches (NP), the Effective Mesh Size (MESH), the Landscape Shape Index (LSI), the Largest Patch Index, Edge Density, and the mean Euclidean Nearest-Neighbor distance (ENN) between patches. The ENN metric, in particular, carries direct ecological meaning: it measures how far one patch of habitat or canopy lies from the next, and thus how connected, or how severed the ecological network of a cell remains. A high mean ENN in a Shadow/Canopy cell signals a grove being slowly atomized into isolated remnants, its buffer function eroding even where its total green area has not yet fallen. Where parcel-scale structural connectivity is read morphologically, the analysis draws on the conceptual apparatus of mathematical spatial pattern analysis (MSPA) and its GUIDOS implementation, distinguishing core, edge, bridge, and islet components of the green network.

Two fragmentation findings shaped the final composite score and are recorded here as methodological corrections. First, the `SPLIT_MEAN` metric, intended to capture subdivision, was found to invert its expected signal in open rural cells: in a cell containing a single large unbroken field, the metric returned values implying high fragmentation, the opposite of the landscape reality. `SPLIT_MEAN` was consequently dropped from the RUTZ score rather than

allowed to corrupt it. Second, an early asymmetric normalization term was found to inflate the scores of open rural cells artificially; it was replaced with a symmetric, two-sided form that treats deviations in both directions consistently. These corrections, like the Level-2 lesson and the Pairwise Intersect lesson, are surfaced rather than buried, because the integrity of the composite index depends on the integrity of every term that enters it.

METHODOLOGICAL FINDING: On a uniform fishnet, Patch Density and Number of Patches are numerically identical (NP is used directly). SPLIT_MEAN inverts the fragmentation signal in open rural cells and was excluded from the composite score. Asymmetric normalization inflates open-rural cells and is replaced with a symmetric two-sided form. A composite index is only as trustworthy as its least-examined input term.

The dominant ecology assignment that closes this step is the culmination of the Phase 1–3 evidence chain. Each cell receives a Score_Pietra, Score_Frangia, and Score_Giardino from the 7-metric morphological scoring (Table 4.3); the winner, whichever ecology scores highest, provided the score reaches the minimum floor of 5 is written to the Dominant_Ecology field. A cell that reaches no floor is Transitional. The provisional 7-metric run returns Stone (4,306 cells, 49.9%), Transitional (3,635, 42.1%), Shadow (465, 5.4%), and Fire (219, 2.5%). The elevated Transitional share relative to the expected range reflects the morphological blind spot for agricultural-collapse Fire: F1 and F4 ecology (72.37% and 10.99% of the composite La Frangia by area) produce an open, low-BSF, low-ISF morphological signature indistinguishable from the Stone matrix. A hidden Frangia diagnostic confirms 1,464 additional cells carry F1 or F4 abandonment flags while classified as Stone or Transitional roughly seven of every eight Frangia-affected cells are invisible to the morphological classifier alone. The two metrics that resolve this (NDVI below 0.15 and normalized LST ≥ 0.65) are admitted in the Full 9-metric run once the Thermal Time-Series bridge fields are populated. With morphology, spectral ecology, and fragmentation all summarized to the hectare, the pipeline closes by composing the five normalized sub-scores — built fraction, impervious fraction, isolation, wall density, and ecological composition (s_bsf, s_isf, s_enn, s_wall, s_ecol) — into the composite Peri-Urban Score, classified by Jenks natural breaks into five categories: Rural Matrix (1,535 cells), Margin Approach (2,107), Transition Mosaic (2,514), Active Margin (1,763), and Critical Fringe (706). The two outermost transitional classes — Active Margin and Critical Fringe, together 2,469 cells — constitute the operational peri-urban band on which the RUTZ Index of Chapter 9 is ultimately constructed. The engine room has produced its output: a fully characterized grid, every cell carrying its morphological, ecological, thermal, and fragmentation signature, ready for the territorial portrait that Chapter 6 will read back out of it.

Chapter 6

CHAPTER 6: Characterizing Lecce's Peri-Urban Gradient

Before numbers can speak, a territory must be read. The five chapters preceding this one have constructed the instruments of analysis, the theoretical framework, the methodological pipeline, the spatial data infrastructure, with the precision of a surgeon preparing tools before an operation. Chapter 6 performs the first incision: it opens the body of the landscape and names what is found inside. It is the portrait that precedes the diagnosis.

Lecce is not a generic Mediterranean city. It is a specific geological, agrarian, and thermal organism, shaped by the peculiarities of the Salento peninsula and the centuries of territorial practice that transformed a limestone shelf into one of southern Italy's most distinctive built and non-built fabrics. To understand why the peri-urban fringe of Lecce functions or has stopped functioning as a climate buffer, or as a moderating cooling generator, first, the geography that made it possible should be understood, the vernacular intelligence that encoded it in stone and soil, the methodology that allows it to be measured, and the typological logic that makes it legible and comprehensible. These are the five tasks of the chapter.

The four fringe prototypes introduced in section 6.5 are not taxonomic endpoints; they are conceptual anchors for the quantitative typology constructed in Chapter 9. The reader moving through this chapter is invited to hold them loosely, as landscape archetypes rather than land use categories, and to understand what the fishnet will later confirm in numbers. This chapter first establishes a spatial argument and categories of conflicts.

6.1 Geographical and Climatic Context: The Salento Peninsula as a Thermal Fact

The Salento peninsula is the southernmost extension of the Italian landmass, a limestone heel projecting into the Mediterranean between the Adriatic Sea to the east and the Ionian Sea to the west. At its widest, the peninsula spans barely forty kilometers between its two coastlines. At its narrowest, the sea is audible and sensed from the fields. This confinement between two marine bodies is not a scenic curiosity; it is shaped by a climatic condition that also shapes every thermal dynamic the thesis investigates.

Lecce sits at approximately 40°20' N, 18°10' E, at an elevation of roughly 49 meters above sea level, a figure that underscores the fundamental flatness of the territory. The Salento peninsula has no mountains, no significant ridges, no topographic corridors that might induce orographic lifting, channel cooling breezes, or generate nocturnal cold air drainage. Its relief is best understood not as a landscape of hills and valleys but as a barely undulating limestone platform, gently tilted toward the sea. The thermal consequences of this flatness

are profound: without topographic modulation, the exchange of heat between surface and atmosphere proceeds at the pace dictated by insolation alone, and in summer that pace is relentless.

Under the Köppen-Geiger classification, Lecce falls within the Csa category, a Mediterranean climate characterized by hot, arid summers and mild, moderately wet winters. The label is accurate but understates the intensity of the summer thermal stress. July mean maximum temperatures regularly approach 32–34°C, while heat wave episodes, increasingly frequent under climate change, drive daytime peaks above 40°C. The summer precipitation deficit is near-total: mean July rainfall in Lecce is typically below 15 mm, a figure that eliminates evapotranspiration and, more importantly, the soil's surface moisture as a significant thermal moderator for all but the most deep-rooted or irrigated vegetation.

The significance of this context for the thesis becomes clear when set against the broader Mediterranean trajectory. The Intergovernmental Panel on Climate Change's Cross-Chapter Paper on the Mediterranean Region documents that atmospheric warming across the basin has exceeded global average rates since the 1980s, with future annual and summer warming rates projected to be 20% and 50% larger than the global annual average, respectively (Lionello & Scarascia, 2018, as cited in IPCC, 2022). Summer warming is projected to be particularly intense in the northern Mediterranean, the zone that includes Puglia, potentially accompanied by increased flash flood frequency and long-term drought spells. For Lecce, this means that the thermal stresses already embedded in its climate baseline will be amplified, not merely continued. The peri-urban buffer this thesis seeks to characterize is therefore not a planning amenity for comfortable decades but a climate-critical infrastructure for dangerous ones.

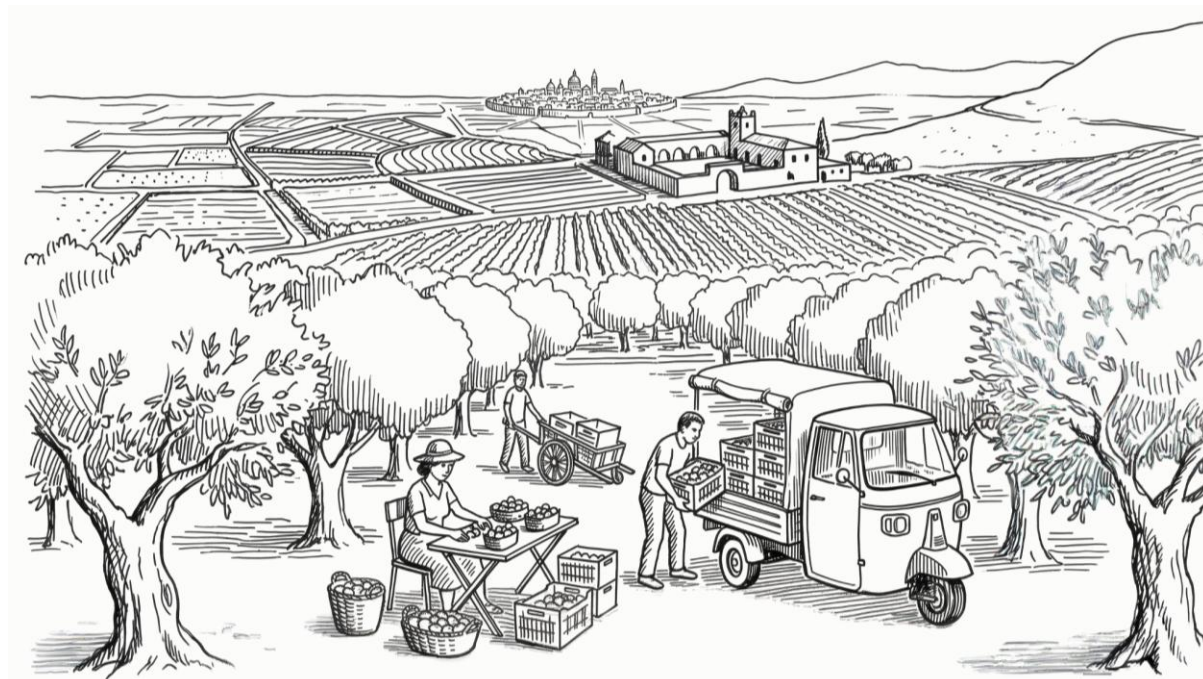
Two maritime exposures further complicate the thermal picture. The Adriatic coast, facing northeast, receives the Bora wind, a cold, dry, descending flow from the north Adriatic, in winter and early spring, providing occasional thermal relief. The Ionian coast, facing southwest, is the avenue of the scirocco: the warm, moisture-laden, sand-carrying wind from North Africa that arrives in spring and autumn, driving temperatures sharply upward and desiccating vegetation. The scirocco is not merely uncomfortable; it is ecologically destructive, accelerating soil moisture loss and stressing the olive groves and herbaceous cover that constitute the thermal buffer's biological substrate. The Salento fringe is thus caught between two seasonal thermal shocks, the northern cold intrusion and the southern heat surge, with the built landscape offering the only structural mediation available.

The limestone geology adds a final layer of thermal specificity. The Apulian karst, known in its Salento variant as *Pietra Leccese*, the creamy, fine-grained calcarenite that defines the region's built fabric, is a high-thermal-mass material. It absorbs heat slowly during the day and releases it slowly at night, attenuating the diurnal temperature swing. This property, shared by the bare karst outcrops that characterize large portions of The Fire ecology (the thermally exposed bare category F2 in the ecology classification), means that the Salento

landscape radiates stored heat long after sunset, a phenomenon that the LST night-time scenes, if available, would confirm spectrally. The same geology that gives Lecce's historic center its luminous stone faces gives its peri-urban fringe its distinctive nocturnal thermal signature.

6.2 Historical Evolution: From Latifundium to Città Diffusa

Figure 6.1 *Salento Peri-Urban Agrarian Landscape*



Note. The Salento peri-urban agricultural landscape: olive harvest at the masseria fringe, with the historic city on the horizon. Digital illustration by Author.

To read the Salento landscape is to read a palimpsest, a document written and overwritten across two thousand years of territorial occupation, in which each successive regime left its morphological script without entirely erasing the one beneath. The three-ecology framework of this thesis, *The Stone*, *The Shadow*, and *the Fire*, is not merely a spatial taxonomy; it is a stratigraphic account of this palimpsest. To understand why these three ecologies exist in their present configuration, one must trace the territorial orders that produced them.

The Roman latifundium was the first great organizing logic. Across the Salento, as across much of southern Italy, vast undivided estates, worked initially by slave labor and later by coloni bound to the land, imposed a pattern of large-scale agricultural production on a landscape previously cultivated at a smaller scale. The latifundium's morphological legacy is the persistence of the large parcel as the basic unit of Salento territory. Even today, the fishnet cells of the Fire ecology contain parcels whose boundaries trace the logic of Roman centuriation, rectangular, oriented, large enough to require labor organization rather than mere household effort.

From the fifteenth century onward, the masseria emerged as the territorial instrument of a new agrarian capitalism. Where the latifundium had organized labor through ownership, the masseria organized it through the estate-compound. This fortified, self-sufficient agricultural complex concentrated residential, productive, and logistical functions within a single morphological unit. The masserie of Salento were not simply farmhouses; they were territorial organisms. Each one radiated outward into a matrix of olive groves, vineyards, grain fields, and cisterns, connected to the others and to the city by unpaved tracks, the tratturi that the thesis's transect intersects repeatedly.

The masseria is the closest analogue, in built form, to the thesis's concept of the climate buffer. Its thick limestone walls, typically 60 to 90 centimeters, function precisely as Pijpers van Esch (2008) describes the thermal behavior of dense, high-mass vernacular architecture: attenuating the diurnal temperature curve, releasing absorbed heat slowly into the night, maintaining interior temperatures significantly below the external maximum (p. 33). Its enclosed courtyard creates a shaded microclimate, a cool island inside the thermal landscape, while its cistern, collecting rainwater from the roof during the wet winter, cools the immediately adjacent air through slow evaporation in summer. The masseria was not designed as a climate device; it was designed as an economic one. But the two functions were historically inseparable.

The post-war transformation ruptured this inseparability. Beginning in the 1950s, the combination of agricultural modernisation, rural-to-urban migration, and the slow but relentless penetration of speculative construction into the peri-urban fringe produced what Indovina (1990) and later Donadieu (2013) identified as the *città diffusa*, the diffuse city, a dispersed, low-density urban expansion that neither followed the logic of the compact historic centre nor produced the coherent suburban fabric of northern European expansion. In Lecce's case, the diffuse city took the form of isolated villas, small residential clusters, and occasional commercial sheds distributed across the remnant agricultural matrix, connected by an infrastructure of provincial roads that served movement without organising settlement.

Donadieu's (2013) *campagne urbaine* framework is instructive here. He identifies three forms that peri-urban agriculture takes in Mediterranean contexts: 'forme ereditate', inherited, durable but fragile agricultural forms that once fed the city; 'forme degradate', degraded forms overwhelmed by urban expansion; and 'forme innovatrici', innovative forms born from the collision of crisis and opportunity (p. 11). All three are visible in the Salento fringe simultaneously. The active olive groves of Il Giardino are 'forme ereditate', ancient productive landscapes performing ecological services that their owners no longer consciously manage. The abandoned parcels of La Frangia are 'forme degradate', territory in suspension, neither actively agricultural nor definitively urban, occupying the liminal condition that the RUTZ Index is designed to measure. The occasional urban garden, the small-scale orchard, the community cultivation plot, these are the 'forme innovatrici',

tentative and isolated, but pointing toward the post-productive landscape that the thesis's design proposals in Chapter 10 will articulate.

One institutional moment deserves specific mention. In 2009, the Municipality of Lecce commissioned the University of Genoa to undertake a consulting research project for the city's new Piano Urbanistico Generale (PUG), coordinated by Mosè Ricci with Jeannette Sordi and an interdisciplinary team (Sordi, 2014). This commission signals that Lecce's planners recognized, at least implicitly, that the existing planning frameworks were inadequate to the morphological complexity of the fringe. The PUG process has produced periodic updates, but the fundamental spatial question, how to read, protect, and activate the peri-urban gradient as a climate-relevant resource, remains open. This thesis is positioned as a methodological contribution to that still-open question.

What the fishnet's F-class ecology designations capture in spectral terms — abandoned agricultural parcels, dry herbaceous abandonment, stalled urban edges — is therefore the morphological residue of this territorial disruption. The 83.4% invisibility of The Fire/Burn ecology to Urban Atlas 2021 is not a technical failure of the European classification system; it is a structural reflection of the fact that the Salento fringe was never urbanized, never fully agricultural, and never planned. It exists in the gap between the category systems that modern spatial governance has available to it. The RUTZ Index is designed precisely to bridge that gap.

6.3 The Built Vernacular: Stone, Geometry, and Passive Climatology

Every territory has its intelligence encoded in its materials. In the Salento, that intelligence is Pietra Leccese, the warm, cream-colored calcarenite that gives the region's buildings their luminosity, its historic center its Baroque extravagance, and its peri-urban fringe its unmistakable visual character. But Pietra Leccese is not merely a cultural symbol. It is, in the precise language of building physics, a climate modifier, and understanding why requires reading it not as ornament but as thermal infrastructure.

The albedo of Pietra Leccese, its capacity to reflect incident solar radiation rather than absorbing and re-emitting it as long-wave heat, varies with surface preparation and weathering but typically ranges between 0.30 and 0.45 for relatively clean, unweathered surfaces. Pijpers van Esch (2008) documents how surface albedo directly governs the temperature of the urban surface: higher albedo reduces surface temperature, which reduces long-wave radiation emission from that surface, which in turn lowers the Mean Radiant Temperature (MRT) and ambient air temperature in the immediately adjacent space (section 5.7.1). A limestone wall in direct summer sun will therefore be significantly cooler to the touch and to the thermal radiation budget of the street than an equivalent concrete or asphalt surface. The Lecce historic center's microclimate advantage over its speculative suburban fringe is partly encoded in this albedo differential.

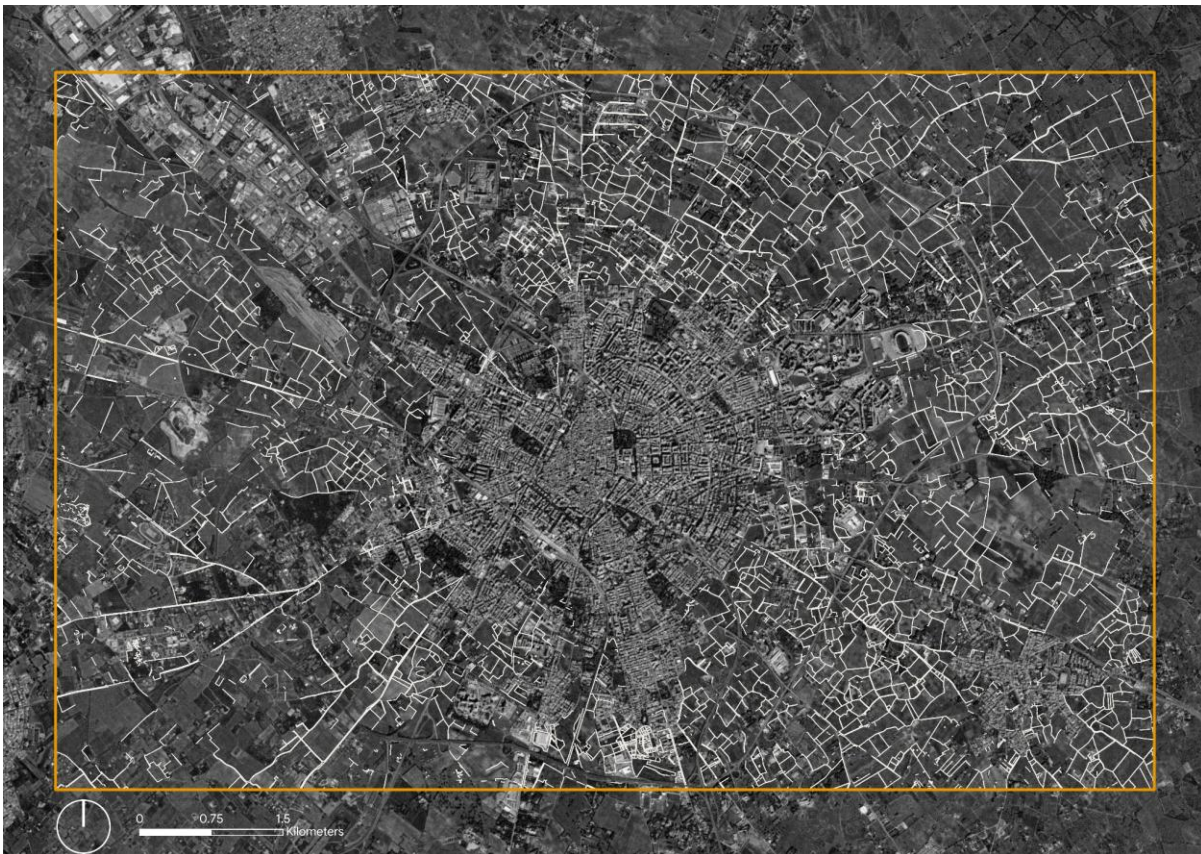
The same limestone property that confers microclimate benefit also generates one of the pipeline's most significant methodological challenges. In the Deep Learning classification workflow documented in section 5.5, bare Pietra Leccese surfaces, building walls, unpaved courtyards, limestone outcrops, and reflected near-infrared wavelengths at levels similar to certain sparse vegetation covers generated false positive classifications that required correction. The material that kept Lecce cool confounded the algorithm that was trying to measure coolness. This irony is not merely anecdotal; it reflects a genuine limitation of spectral indices calibrated for temperate or tropical contexts when applied to Mediterranean limestone landscapes, and it is documented in the thesis as a methodological finding rather than a procedural failure.

Beyond the building mass, the Salento fringe carries two vernacular infrastructure types whose climate relevance has been consistently undervalued in contemporary planning practice: the pajara and the muretto a secco.

The pajara (plural: pajare) is a conical dry-stone hut, built without mortar through a corbelling technique that closes the circular plan with progressively overhanging courses of stone until they meet at a point. Pajare are scattered across the Salento agricultural landscape in their hundreds, occasionally isolated, sometimes clustered at field junctions, often embedded in the muretto secco networks that subdivide the territory. Their function was ostensibly practical: storage of agricultural tools, temporary shelter during fieldwork, and ventilation of harvested produce. Their thermal performance, while never formally measured for the pajara specifically, can be inferred from structurally analogous trullo of the Itria Valley: Baldinelli et al. (2017) demonstrated that the double-skin limestone construction with rubble core produces indoor summer temperatures in trulli without mechanical cooling, with field reports documenting interior-to-exterior temperature differences of 7-10°C under peak summer conditions (Fragnelli, cited in AFP, 2026). The pajara's thinner walls (60-80 cm versus the trullo's 1.5-3 m) would produce a more modest attenuation, but the construction principle is identical, unmortared joints allowing natural convection, high thermal mass absorbing and phase-shifting the diurnal heat signal, and the absence of windows minimizing direct solar radiation. The pajara is, in the most precise sense, a passive cooling device refined over centuries of experimental practice.

The muretti a secco, the dry-stone walls that subdivide the Salento agricultural matrix into parcels, delineate property boundaries, and frame the tratturi, are perhaps the most climatically significant elements of the peri-urban fabric. Donadieu (2013) writes explicitly of how 'i muri a secco hanno funzionato come stoccaggio e riciclaggio dello spietramento dei campi e oggi diventati il logo del paesaggio mediterraneo' (p. xxxiii), the walls encoded in spatial form the centuries of manual labour by which farmers cleared their fields of the karst limestone that obstructed cultivation. They are simultaneously agricultural technology and landscape archaeology.

Figure 6.2a Dry-stone wall structures across the study area

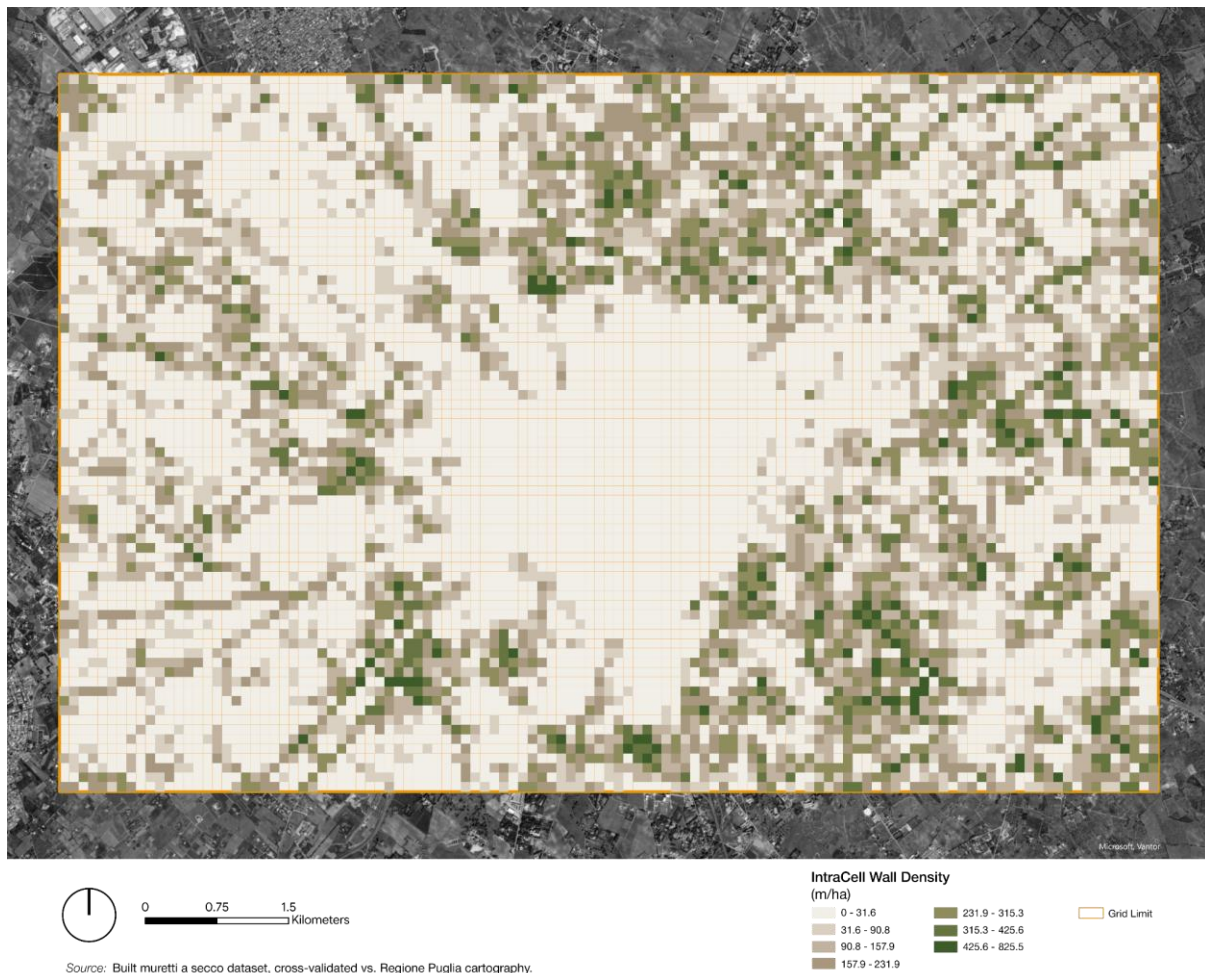


Note. The network of vernacular dry-stone walls and their relation with the built and unbuilt fabric across the study area.

But they are also ecological infrastructure of a particularly sophisticated kind. West-facing walls absorb afternoon solar radiation and re-radiate it as long-wave heat overnight, creating a nocturnal warm-air zone on their leeward side that moderates frost risk for adjacent olive trees. In the scirocco season, they act as wind barriers, reducing the evapotranspiration stress on vegetation and maintaining soil moisture gradients that support the herbaceous ground cover critical to the territory's ecological network. Their unmortared construction supports a specific community of lithophytic plants, invertebrates, and small vertebrates — lizards, field mice, solitary bees- that constitute the backbone of the pollination and soil-formation services the olive matrix depends upon.

The unique muretto a secco dataset developed for this research, hand-verified against Google Street View, covering the full extent of the nine-municipality fishnet, measuring wall density in meters per hectare at the 100m cell level, captures this infrastructure in quantitative form for the first time in the study area. The Neighbor Wall Density and IntraCell Wall Density fields in the FISHNET_Master_Profile encode not merely a land feature but a climate-relevant ecological network. Cells with high wall density in The Fire/Burn ecology correspond, in the thermal analysis of Chapter 7, to lower summer LST values, a relationship that is one of the thesis's core empirical findings.

Figure 6.2b Wall Density Choropleth: IntraCell Muretto a Secco Network across Peri-Urban Fishnet, Lecce



Note. IntraCell wall density (meters of muretti a secco per hectare) across the 8,625-cell RUTZ fishnet. High-density cells (dark register) concentrate in the Stone ecology karst matrix; the almost complete absence of wall density in Fire ecology cells is legible as white voids at the peri-urban interface, confirming the vernacular infrastructure's role as both a thermal and ecological-network indicator. Wall density values derived from the author-built muretto a secco dataset, hand-verified against Google Street View and cross-validated against Regione Puglia spatial data. Field: IntraCell Wall Density (m/ha),

Taken together, the Pietra Leccese thermal mass, the pajara's passive cooling, the muretti a secco's ecological-thermal network function, and the Salento vernacular represent a landscape architecture of climate mitigation that was never theorized as such, but that preceded the language of resilience by several centuries. What this thesis argues is that these elements are not heritage elements to be preserved in amber but functional climate technologies to be read, mapped, and integrated into contemporary planning frameworks. The RUTZ Index's ecology composition variables, particularly the F-class and G-class ecological assignments, and the wall density metrics, are designed to capture exactly this functional intelligence.

6.4 The Transect Methodology: Reading the Gradient as a Biophysical Continuum

A gradient is not a line. It is a story about how one condition becomes another, gradually, unevenly, with reversals and plateaus and sudden ruptures. The peri-urban gradient of Lecce, moving from the dense limestone core of the historic center outward through the dispersed fabric of the Fire ecology to the open agricultural and karst matrix of the deep rural, is exactly this kind of story. The transect is the methodology's attempt to read it.

The analytical framework of this thesis is built around a 100-meter fishnet grid covering 8,625 cells and approximately 86 km² of the nine-municipality study area. Each cell is a unit of observation rather than a unit of territory; it holds simultaneously the morphological signature of its built form (BSF, ISF, fragmentation metrics), the ecological composition of its land cover (Dominant Ecology, F- and G-class shares, crop type proportions), and the thermal record of its surface temperature across twelve Landsat scenes spanning 2015 to 2025. The cell is not an administrative unit; it does not respect property boundaries or municipal borders. It is defined purely by the geometry of observation: one hectare, consistent across the entire study area, at the scale at which land use transitions become legible in the Collection-2 Level-2 Landsat data.

The transect logic, the reading of the grid not cell by cell but as a gradient from urban core to deep rural, follows the methodological tradition of the ecological transect, in which a structured transect through heterogeneous territory is used to expose the biophysical gradient more clearly than a random or stratified sample would. In the RUTZ context, the transect is operationalized through the Peri-Urban Score and Peri-Urban Class variables: the composite score (built from normalized BSF, ISF, ENN, wall density, and ecology composition sub-scores) places each cell on a continuum from fully built to fully rural, and the Jenks natural-break classification into five classes identifies the gradient's structural inflection points.

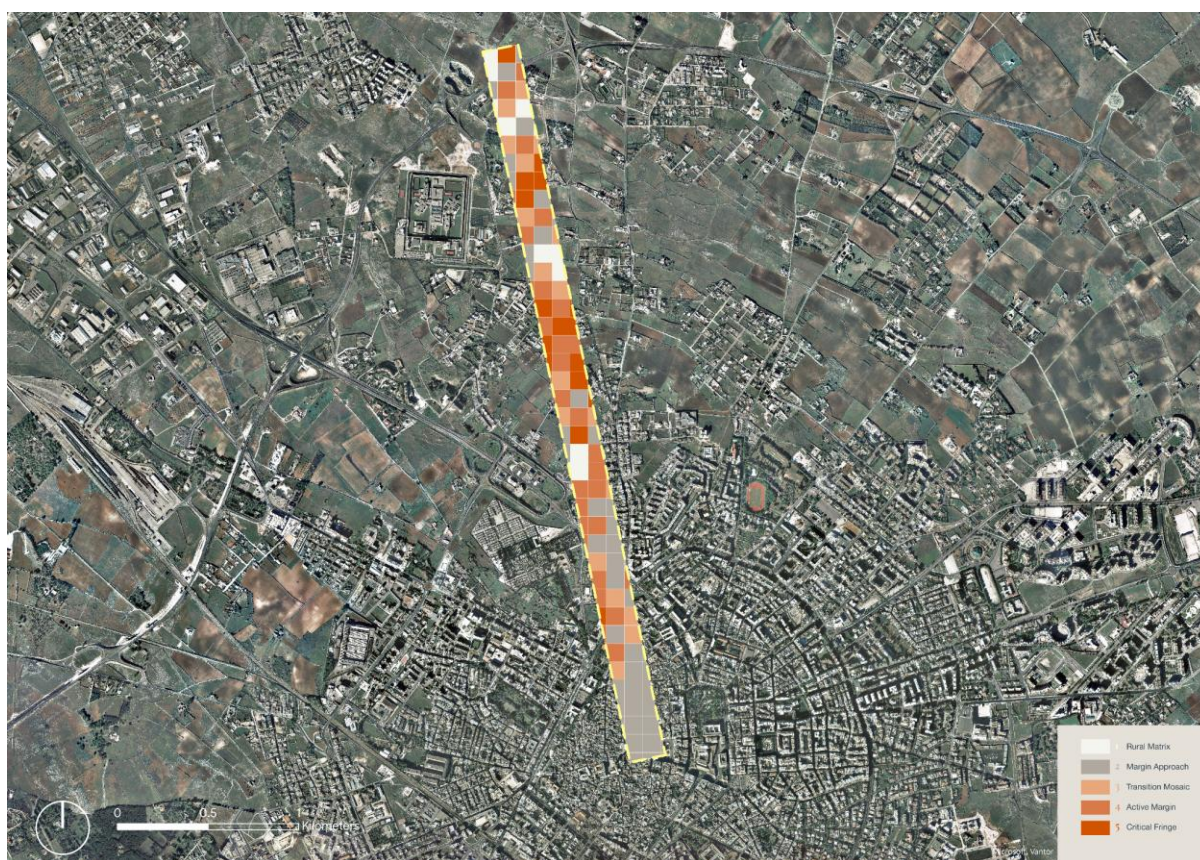
A methodological honesty is required here. The transect imposes a geometric linearity on a territory that is fundamentally non-linear. The Fire/Burn ecology is not a band of uniform character encircling the city; it is a mosaic, fine-grained, interrupted, spatially heterogeneous. Individual cells in the same Peri-Urban Class may exhibit radically different ecological compositions, thermal signatures, and morphological configurations depending on their position relative to road corridors, historic land ownership patterns, and the legacy of individual masseria estates. The transect captures the statistical signature of this mosaic, the average gradient, the modal conditions, the boundary between thermal exposure and buffer capacity, but it does not capture its spatial particularism.

This limitation is acknowledged not to undermine the methodology but to frame it correctly. The RUTZ Index is a gradient-reading instrument, not a parcel-scale planning tool. Its appropriate application is at the territorial scale, identifying which zones of the fringe carry buffer capacity, where that capacity is being eroded, and what planning interventions could

reinforce it. The cell-level detail is the evidence base for these territorial arguments, not the territory itself.

The 200-by-4000-meter transect design, within the larger fishnet framework, reflects a specific biophysical rationale. The 4000-meter length spans the full transition from compact historic urban tissue to deep rural landscape in Lecce's morphological context, while the 200-meter width provides statistical robustness at the cell level without averaging over zones so large that gradient transitions are blurred. For the study and intervention proposal, a sampling stack profile, positioned along the transect, aside from data extracted from the fishnet grid's data.

Figure 6.3 Peri-Urban Transect Corridor: 200×4,000m Study Section, Lecce Fringe



Note. Ortofoto crop of the 200×4,000m peri-urban transect corridor, oriented north (Tangenziale ring road and industrial zone) to south (dense historic core). The corridor captures the full morphological and ecological transition that the RUTZ fishnet measures: sealed industrial and low-density residential fabric in the northern section; the contested agricultural–built interface of the Active Margin and Critical Fringe in the central band. Orthophoto source: SIT Puglia / Ortofoto AGEA 2019, approximately 0.5m resolution.

The bivariate map of BSF and ISF across the study area, positioned in Chapter 7's morphological analysis, provides the spatial foundation for the transect reading. High BSF/high ISF cells correspond to the Stone ecology; low BSF/low ISF with high ecological diversity corresponds to The Shadow ecology; the intermediate and conflictual combinations characterise The Fire/Burn ecology.

6.5 Typological Classification: Four Lecce Fringe Prototypes

Classification is always an act of interpretation. When the fishnet assigns a cell a Peri-Urban Class, it makes a quantitative statement about the composite configuration of its morphological and ecological variables. But cells are not configurations; they are places. And places carry histories, functions, and vulnerabilities that no composite score fully captures. The four fringe prototypes introduced in this section are the bridge between the quantitative classification and the qualitative argument: they translate statistical clusters into spatial archetypes that the reader and the planner can recognise in the landscape.

The typological framework adapts the laquinta and Drescher (2000) conceptualisation of peri-urban space, which identified a spectrum of transitional forms between fully urban and fully rural, as the organisational scaffold. Applied to the Lecce context and calibrated against the fishnet data, four prototypes emerge as analytically and planimetrically distinct.

The first prototype is the low-density sprawl type, the dominant mode of post-war expansion in Lecce's outer fringe. Cells of this type exhibit low BSF (typically below 0.15), elevated ISF (frequently above 0.40), fragmented and isolated vegetation patches, minimal wall density, and NDVI values in the 0.15–0.30 range that indicate sparse, stressed, or seasonally absent vegetation. The built form is characterized by isolated villas and small residential blocks on former agricultural plots, buildings that arrived individually, without coordinated infrastructure, in an agricultural matrix that they fragmented without replacing. In Donadieu's (2013) terminology, these are the 'forme degradate', territory that has been reached by urban expansion without being meaningfully urbanized. Thermally, this type is the most exposed: no shade canopy, impervious surfaces absorbing maximum insolation, no wall networks moderating the nocturnal radiation balance. The summer LST of low-density sprawl cells consistently exceeds that of adjacent vegetated fringe cells by 3–6°C in the fishnet data.

The second prototype is the vegetated buffer type, the ecology that the thesis identifies as The Shadow ecology, and the spatial argument for the buffer's existence. These cells exhibit low to moderate BSF (below 0.10), very low ISF (below 0.20), high NDVI (0.40–0.60), strong wall density, and an ecological composition dominated by the G1 (Active Olive Grove) and G3 (Herbaceous Mosaic Functional) classes. The Broadleaved Forest class (G2), where it appears, corresponds to the transitional woodland patches that occupy degraded but ecologically recovering fields on the urban margin. This prototype is the most climatically competent of the four: its olive canopy provides direct shading and transpiration cooling; its muretto a secco network moderates wind and provides ecological connectivity; its low imperviousness fraction means that summer precipitation, however negligible, infiltrates rather than runs off. The vegetated buffer type is also the most threatened: its land values

are rising, its regulatory protection is minimal, and its ecological services are nowhere formally recognized in the municipal planning instruments.

The third prototype is the degraded industrial fringe type, the least ecologically coherent and thermally most hostile condition in the fringe. Cells of this type carry high ISF (above 0.50), near-zero NDVI, minimal wall density, and a land cover dominated by the Discontinuous Dense Urban Fabric and Arable Land categories in the CLCbackbone 2023 dataset, with the arable fraction typically representing recent conversion of agricultural land to logistics or artisanal industrial use. These cells are concentrated near the ringroad corridors that radiate from Lecce toward Brindisi, Otranto, and Gallipoli, infrastructure axes that have attracted warehouse and commercial development in the post-2000 period. Their LST values in the 2021 and 2025 summer scenes are consistently among the highest in the fishnet, often approaching the thermal maximum of the fully built urban core. Unlike the historic centre, however, these cells offer none of the compensating albedo benefit of Pietra Leccese; their surfaces are asphalt, corrugated metal, and exposed concrete.

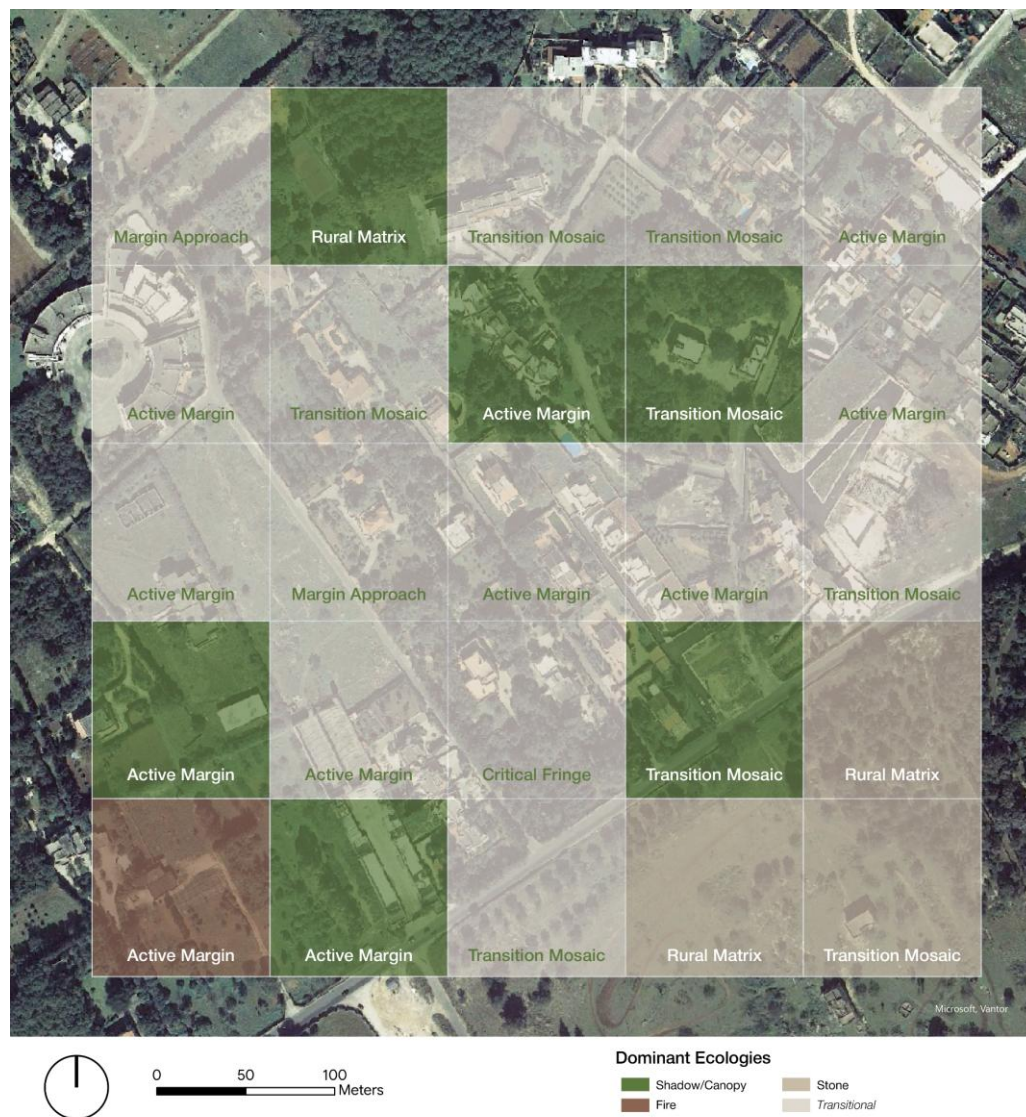
The fourth prototype is the historic masseria matrix type, the palimpsest prototype, the one that carries the deepest ecological memory and the greatest unrealized climate potential. Cells of this type are characterized by the presence of one or more masseria complexes within or immediately adjacent to the cell boundary, surrounded by remnant olive grove matrix, interspersed with muretti a secco networks, and exhibiting moderate BSF (0.10–0.20) and low ISF (below 0.25). Their NDVI values are moderate but consistent; the olive canopy, even when partially abandoned and under *Xylella* stress, maintains a photosynthetically active green mass through the summer dry season. The masseria buildings themselves, thick-walled, vaulted, oriented with courtyards toward the prevailing breeze, are the embodiment of the passive climate architecture described in §6.3. Yet this prototype is also, paradoxically, the most legally vulnerable: masserie are frequently eligible for conversion to tourist accommodation or residential use under regional legislation, and their agricultural context, the defining element of their ecological value, offers no formal protection once the building use changes.

These four prototypes are not exhaustive categories. The fishnet's 8,625 cells contain more morphological variety than four types can capture, and many cells combine elements of multiple prototypes, a sprawl-type residential plot adjacent to a masseria ruin within a vegetated fringe, for example. The prototypes function as conceptual attractors, not rigid containers. They organise the qualitative reading of the fringe in a form that the quantitative analysis of Chapter 7 can test, refine, and ultimately supersede through the RUTZ Index's continuous composite score.

What the four prototypes collectively argue is this: the Lecce fringe is not chaotic. It is morphologically legible, ecologically stratified, and thermally differentiated. Its apparent disorder, the mixed-up scatter of villa blocks, abandoned groves, masserie, and industrial warehouses, and extraction mines resolves, at the 100-meter scale of analysis, into a

structured gradient of buffer capacity. The planning failure has not been the production of chaos but the failure to read the order that already exists. This chapter's task has been to make that order legible. The chapters that follow will measure it.

Figure 6.4 A Lecce Fringe Prototype, Orthophoto Crops with Dominant Ecology and Peri-Urban selected cells overlap



Note. A panel of 500×500 m orthophoto crop: low-density sprawl, vegetated buffer, degraded industrial fringe, villa blocks, each with its Dominant Ecology overlay and Peri-Urban Class value. Source: SIT Puglia / Ortofoto 2019 AGEA.

6.6 Peri-Urban Gradient Construction: From Score to Five-Class Ladder

The four prototypes described in section 6.5 are conceptual anchors: legible, nameable, and deliberately not exhaustive. Between the intact masseria matrix and the degraded industrial shed, between the active olive buffer and the stalled construction void, lies the actual fringe: a continuous field of mixed condition that no prototype can claim wholly and no binary classification can hold without distortion. Reading that field as a gradient, measuring, at every hectare, how much of the transition condition a cell carries, is the RUTZ Index's

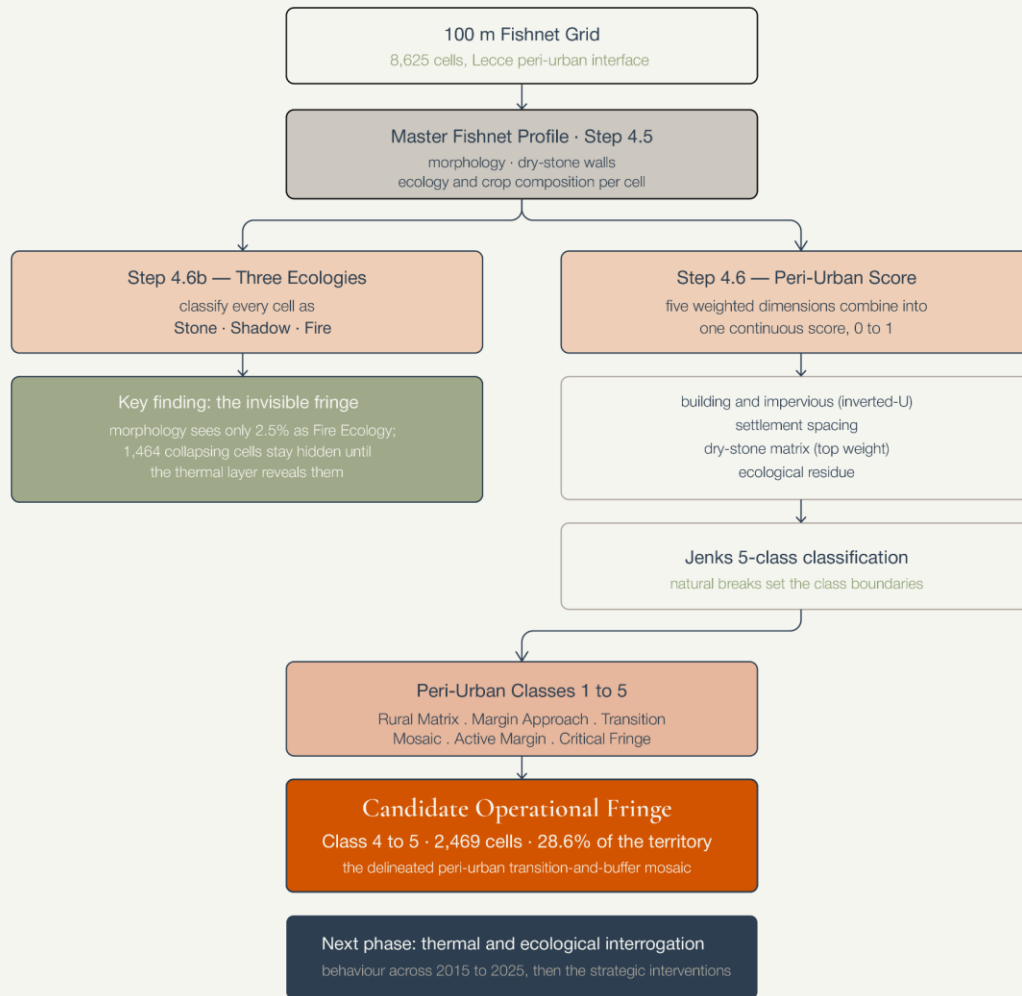
primary territorial operation, formally constituted in Chapter 4 and executed in Chapters 5 and 9. This section makes that gradient visible for the first time, not as a formula but as a territorial map: Figure 6.7.

The composite peri-urban score draws on five normalized sub-scores, each measuring a distinct dimension of the fringe condition at the cell scale. Two record what has been committed to construction and sealed against the moisture cycle: built surface fraction measures how much of the hectare is covered by building footprints; impervious surface fraction measures the total sealed surface, including roads, driveways, and paved yards. A third sub-score captures ecological isolation: the Euclidean nearest-neighbor distance between surviving vegetation patches registers how far the fragments of canopy must reach to sustain the moisture exchange and thermal continuity of a functioning buffer network. A fourth records the dry-stone wall infrastructure — meters of muretti a secco per hectare, the indicator that standard classification frameworks have no instrument to read and that carries the most specific territorial signal of Stone ecology's functional identity. The fifth distills the Phase 1–3 cross-validated land cover evidence into a single fractional variable: the balance between Fire-type and Shadow-type coverage within each cell, encoding the abandonment and canopy evidence that satellite imagery alone cannot resolve. Figure 6.5 traces the pipeline from these five inputs through normalization and weighting to the classified output.

Figure 6.5 The Phase 4 Peri-Urban Gradient Pipeline: From Sub-Scores to Five-Class Classification

Phase 4: Peri-Urban Cell Identification

Process roadmap · how the Master Fishnet becomes a delineated transition zone



Note. Schematic of the four-step Phase 4 pipeline, from the computation of five normalized sub-scores through symmetric two-sided normalization, weighted composition, and Jenks natural-breaks classification into the five-band peri-urban gradient. The ecology composition sub-score is derived from Phase 4.6b Dominant Ecology indicators (Fire-type and Shadow-type coverage proportions from the cross-validated Phase 1–3 ecology composite).

One candidate metric was computed and deliberately removed. The average splitting index, intended to capture the subdivision of vegetation patches, inverted its signal in open rural cells: it read a continuous agricultural matrix — the fringe's most intact configuration as highly fragmented, producing precisely the opposite of its theoretical function. Dropping it is not a gap in the methodology but its integrity: a composite instrument is only as trustworthy as its willingness to remove a variable that lies.

The five retained sub-scores are normalized to a common scale using a symmetric two-sided form, so that wall density measured in meters per hectare and impervious fraction measured as a proportion can enter the same arithmetic on equal terms. An earlier

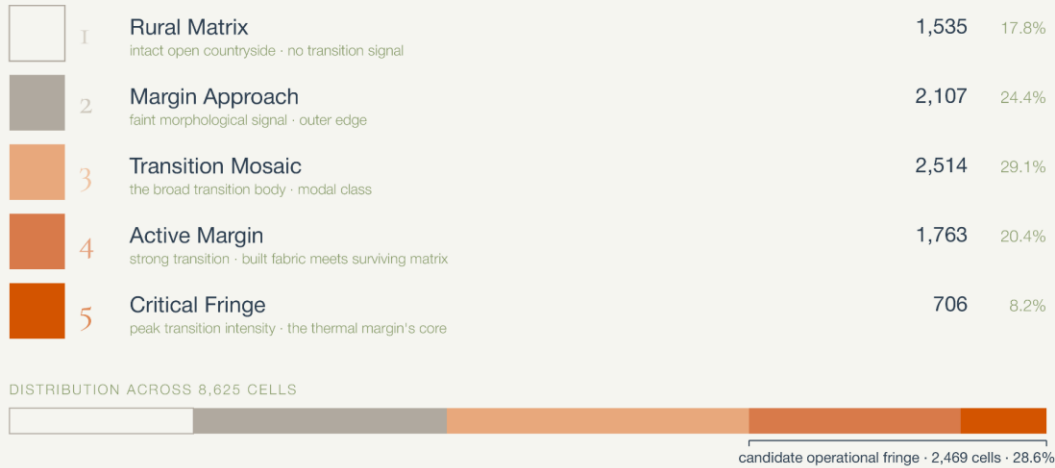
asymmetric formulation systematically inflated the scores of open rural cells, misreading their very openness as a peri-urban signal, and was corrected before classification. The weighted composite is then classified into five ordinal bands by Jenks natural breaks: an algorithm that draws its class boundaries at the data's own structural discontinuities rather than at arbitrary arithmetic intervals. In a strongly right-skewed score distribution, most cells sit low; a thin tail of intensely transitional cells extends to the right — Jenks respects the clustering that the territory actually produced.

The five classes are not interchangeable degrees on a neutral continuum. Each name a distinct territorial condition, and each has its own thermal biography that Chapter 7 will read. The Rural Matrix (Class 1: 1,535 cells, 17.8% of the study area) is the deep buffer: continuous karst-and-agricultural fabric in which no sub-score reaches a level diagnostic of the fringe condition. These cells hold the thermal logic that the thesis is built around — the moisture reserve, the intact canopy, the dense wall network, and their protection is the first planning imperative that the RUTZ Index identifies. The Margin Approach (Class 2: 2,107 cells, 24.4%) introduces the first transition signals: modest sealing, slight ecological fragmentation, the beginnings of Fire-type composition at cell margins. The buffer is still performing here, but the first indicators of stress are legible in the data. The Transition Mosaic (Class 3: 2,514 cells, 29.1%) is the body of the gradient, the largest class by cell count and the one that resists any single typological label. Two or more sub-scores are elevated in every Transition Mosaic cell, the ecological composition is contested between Fire and Shadow indicators, and the morphological condition is precisely the heterogeneous mosaic that standard classification frameworks dissolve into oversized typological blocks. The RUTZ gradient reads it as the contested centre of the fringe, the territory where the outcome of the buffer argument is still open.

Figure 6.6 Five-Class Peri-Urban Gradient: Class Labels, Cell Counts, and Colour Register

Peri-Urban Cell Identification

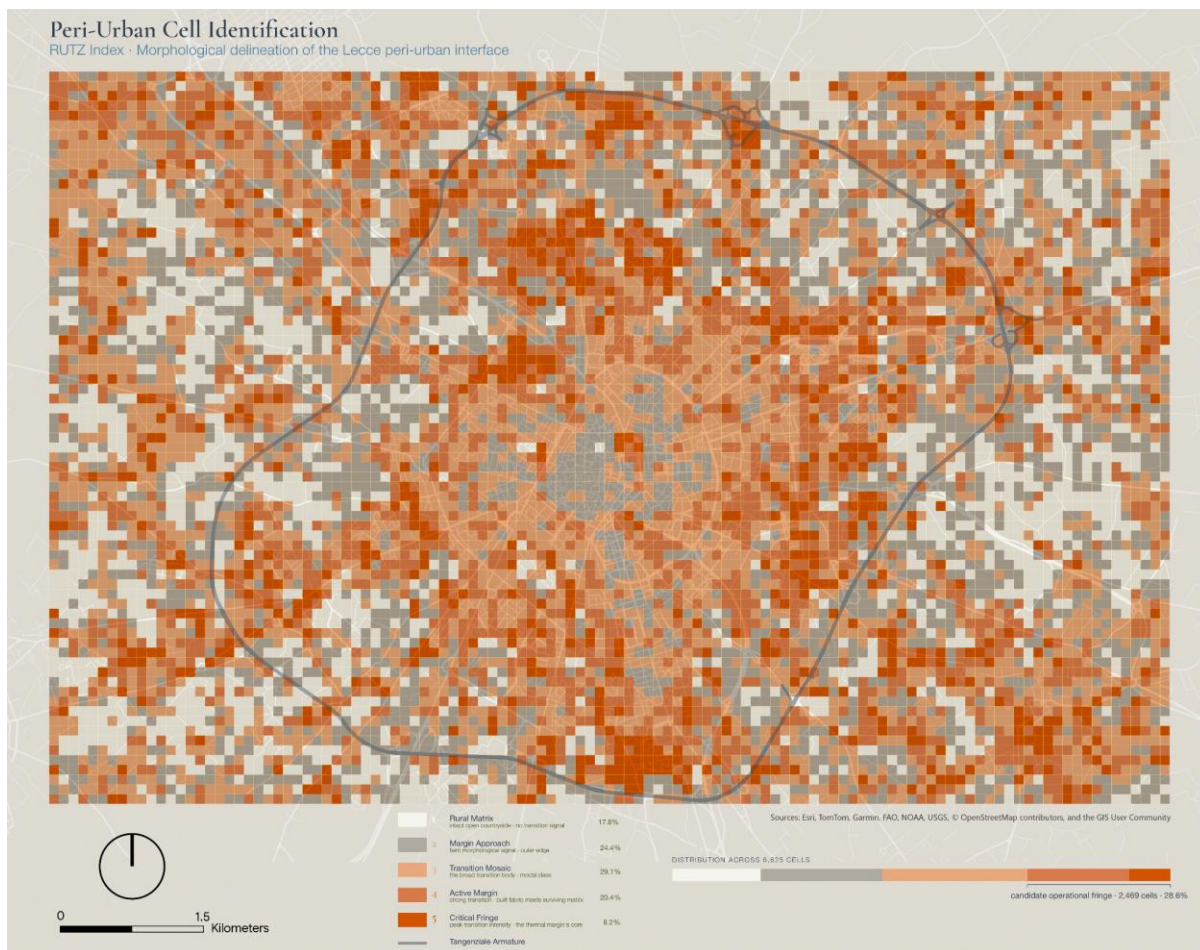
RUTZ Index · Morphological delineation of the Lecce peri-urban interface
8,625 cells · 100 m fishnet · EPSG:32634 · five-class Natural-Breaks (Jenks) classification



Note. The RUTZ peri-urban gradient classification: five Jenks natural-break classes from Rural Matrix (Class 1, $n = 1,535$; 17.8%) through Critical Fringe (Class 5), together constituting the full 8,625-cell study grid. Classes 4 and 5 form the operational peri-urban band. Margin Approach (Class 2) is considered to be the discontinuous and continuous built fabric.

The two highest classes together constitute the operational peri-urban band. The Active Margin (Class 4: 1,763 cells, 20.4%) carries elevated sealing, significant fragmentation, and ecology composition dominated by Fire-type flags. This is the territory where the buffer is failing rather than only stressed, where the sub-score pattern is no longer ambiguous but where planning intervention can still reverse the trajectory that they are following. The Critical Fringe (Class 5: 706 cells, 8.2%) is the acute operative edge: the cells where all five sub-scores converge on maximum peri-urban condition simultaneously, where ecological coherence has been most completely severed, and where thermal exposure in summer reaches the highest intensities recorded anywhere in the grid. Together, Classes 4 and 5 cover 2,469 cells, 28.6% of the study area, and the class ladder closes with their union. It is this band that Chapter 9 calibrates as the RUTZ Index's primary operational domain and that Chapter 10's design proposals address directly. Figure 6.6 presents the five-class legend that accompanies the territorial choropleth.

Figure 6.7 Peri-Urban Gradient Five-Class Classification



Choropleth map of the five-band peri-urban gradient across the 8,625-cell RUTZ fishnet.

What the gradient does, taken as a whole, is convert the qualitative portrait assembled across sections 6.1–6.5 into a measurable, cell-by-cell spatial field. The four prototypes of the preceding section appear within this gradient as concentrations rather than categories: the degraded industrial fringe clusters in Classes 4 and 5; the vegetated buffer concentrates in Classes 1 and 2; the historic masseria matrix; and the urban built fabric is distributed across Classes 2 and 3, depending on the condition of its surviving olive context and the fragmentation status. Each prototype remains legible inside the gradient, but the gradient reveals the continuous spatial logic connecting them, the territorial argument that the fringe is not a scatter of isolated conditions but a structured field of transition intensity whose character can be measured, mapped, and acted upon. The planning failure the thesis addresses has not been the production of disorder but the absence of an instrument capable of reading the order that was always there.

The ecology composition sub-score that feeds this composite, the normalized balance between Fire-type and Shadow-type ecologies coverage within each cell, is presented in full analytical detail in section 7.2, where the three ecologies appear as territorial diagnoses in their own right rather than as inputs to a gradient calculation. The two classification systems are therefore best read as parallel descriptions of the same 8,625 cells: the peri-

urban class categories answer how transitional each cell is; the ecological typology answers which metabolic logic it follows. That the two are computed from a shared evidence base is not a circularity, but it is the empirical argument that morphological structure and ecological identity co-vary across the Lecce fringe in a non-random, interpretable pattern, and that the same 100-meter cell can be read simultaneously through the lens of gradient intensity and through the lens of ecological character without contradiction.

Chapter 7

Chapter 7 — Quantitative Analysis: Morphology, Ecology, and Thermal Performance

The instruments are built and the territory has been read. Chapters 4 and 5 constituted and executed the method; Chapter 6 drew the portrait of the Salento fringe in geological, agrarian, and vernacular terms. This chapter is where the grid begins to speak. It reads the 8,625-cell output of the pipeline along three registers morphological, ecological, and thermal, and arrives at two empirical findings on which the rest of the thesis builds: that the thermal behavior of the Lecce fringe is seasonally inverted rather than fixed, and that the operational peri-urban band, the Active Margin and Critical Fringe cells where intervention is justified, exhibits its own distinct multi-year change trajectory between 2015 and 2025 that the rural matrix and the urban core do not share.

Two datasets carry the analysis. The static **Master Profile** fishnet supplies each cell's morphological identity, ecological classification, and peri-urban class. The dynamic **Thermal Time-Series** fishnet supplies each cell's behavior across twelve Landsat 8/9 Collection-2 Level-2 scenes spanning four years (2015, 2018, 2021, 2025) and three seasons (spring, summer, winter), for a full suite of thermal and spectral indices — LST, five SUHI variants, UTFVI, SMI, TVDI, NDVI, NDBI, Albedo, SAVI, BSI, BLR, and NDMI. The two are joined on the cell identifier, so that a slow morphological identity can be tested against a fast thermal record. That test is the work of this chapter, and its answer is the subject of sections 7.3 and 7.5.

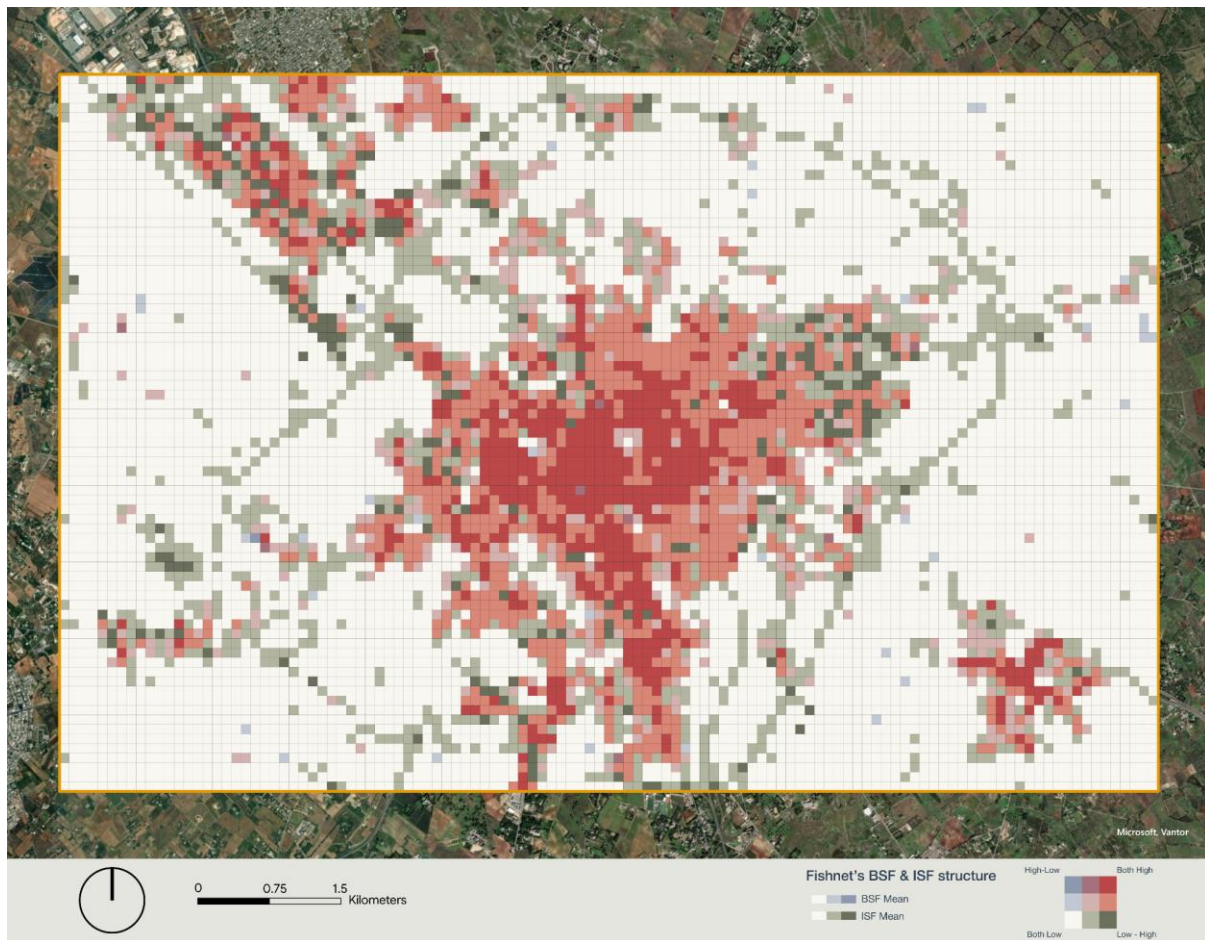
7.1 Morphological Mapping: Built Form, Sealing, and Fragmentation across the Grid

Before the territory is read thermally, it must be read morphologically, because morphology is the structure onto which the thermal signal is inscribed. The four ecologies separate cleanly along every morphological axis the pipeline measures, and the separation already unsettles the intuition the names invite. The **Fire** ecology; the conflictual, abandoned, stalled-construction fringe carries the highest built and sealed fractions in the study area (mean BSF 0.19, ISF 0.79) and the most shattered patch structure (mean number of patches 14.2). The **Stone** ecology, by contrast, sits almost at the origin of the density space (BSF 0.001, ISF 0.04): it is not built fabric at all but the open, dry-stone-walled karst matrix, carrying by far the densest wall network in the grid (117 m/ha of muretti a secco, against 28.5 m/ha in Fire). The **Shadow/Canopy** ecology occupies the low-built, moderately sealed middle, and the **Transitional** class spreads across the gradient body between them.

This is the first corrective the data delivers, and it must be stated plainly because it conditions everything that follows. Empirically, Stone is the *open* ecology and Fire the built one, the inverse of what a reading anchored only on the historic limestone core would

suggest. The dry-stone wall density that defines Stone is not a relic ornament; it is the signature of a continuous agrarian karst matrix, and it is precisely this openness, as section 7.3 will show, that makes Stone the summer thermal pole. The morphological signatures of the four ecologies are summarized in Figure 7.2; the cell-by-cell distribution of built and sealed fraction across the study area is mapped in Figure 7.1.

Figure 7.1 BSF-ISF Bivariate Choropleth



Note. Cell-by-cell bivariate choropleth of Building Surface Fraction and Impervious Surface Fraction across the 8,625-cell study area. Fire fringe cells concentrate in the high-BSF, high-ISF quadrant; Stone karst cells sit at the origin. Source: author's analysis; building footprints OpenStreetMap via Geofabrik.

Figure 7.2 Morphological Signatures of the Four Ecologies



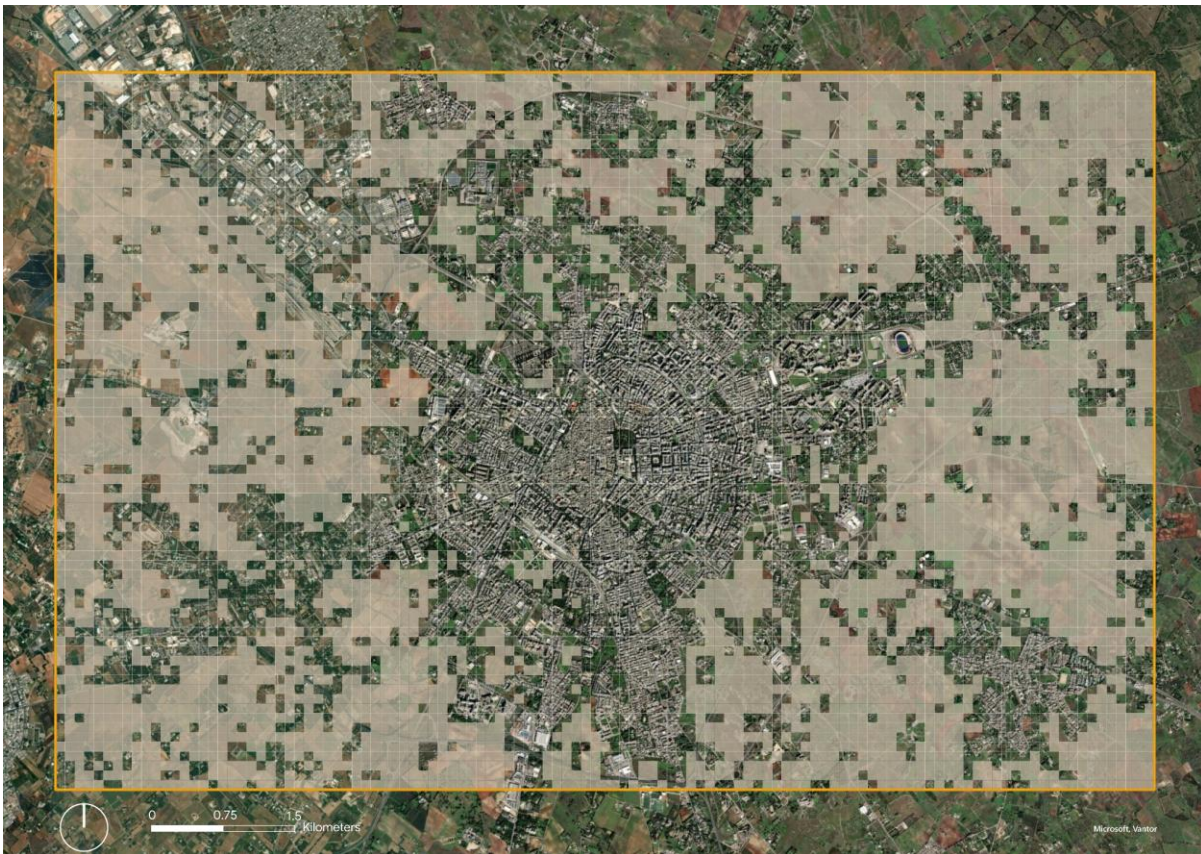
Note. Mean Building Surface Fraction, Impervious Surface Fraction, dry-stone wall density (m/ha), and number of patches for each dominant ecology. Stone is the open, wall-gridded karst matrix; Fire is the built, sealed, most-fragmented fringe.

Fragmentation tracks the same logic. Stone is effectively continuous (number of patches below one per cell, largest-patch index near zero because there is no built patch to index); Fire is the most fragmented, its mean of fourteen patches per hectare recording the interleaving of sealed driveway, stalled foundation, abandoned parcel, and surviving grove fragment that Chapter 6 described as the recurrent configuration of the conflictual fringe. Fragmentation, here, is not noise; it is the measurable morphological fingerprint of the speculative-abandonment process.

7.2 The Three Ecologies as Territorial Diagnosis

Before the four ecologies are read against the thermal record, they must be presented as the diagnostic categories they are, each on its own terms. The chapter therefore opens its ecological reading with three analytical maps — one per ecology in isolation, each exported from ArcGIS Pro analytical reading at the precise classification of the Master Profile, with the cells of the relevant ecology shown against the agricultural and karst baseline at full geographic fidelity (Figures 7.3a, 7.3b, 7.3c). These analytical maps stand for the rigor of the classification itself: each Fire cell is a cell that survived multi-source cross-validation, each Shadow cell carries the spectral and ploughing-indicator evidence of active canopy, and each Stone cell sits in the karst-and-wall matrix that Chapter 6 named.

Figure 7.3a Stone Ecology cells only (Analytical map)



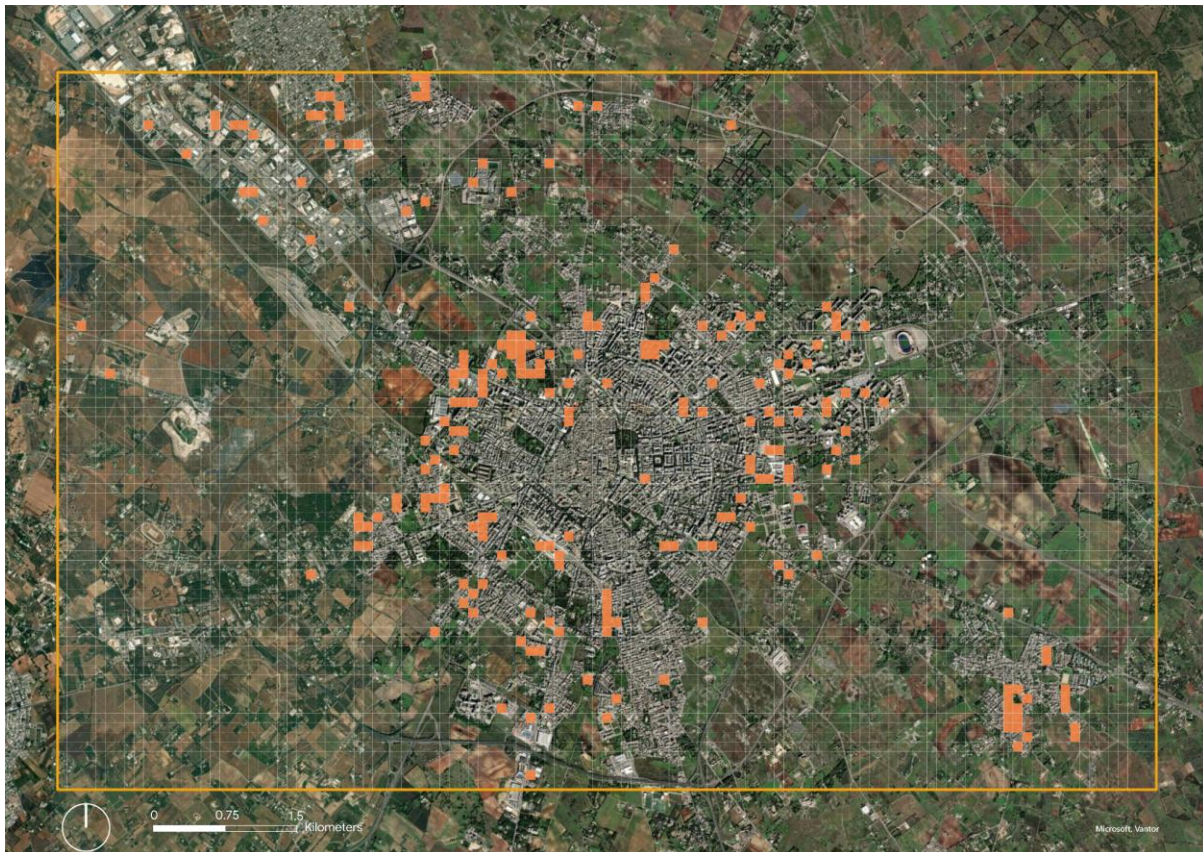
Note. Distribution of Stone-classified cells across the 8,625-cell study area, displayed against the agricultural and karst baseline. $n = 4,306$ cells (49.9% of grid). Source: author's analysis; Master Profile dominant-ecology field.

Figure 7.3b Shadow Ecology cells only (Analytical map)



Note. Distribution of Shadow/Canopy-classified cells. $n = 465$ cells (5.4% of grid). Subclasses G1–G4 in tonal gradation. Source: author's analysis; Master Profile dominant-ecology field.

Figure 7.3c Fire Ecology cells only (Analytical map)



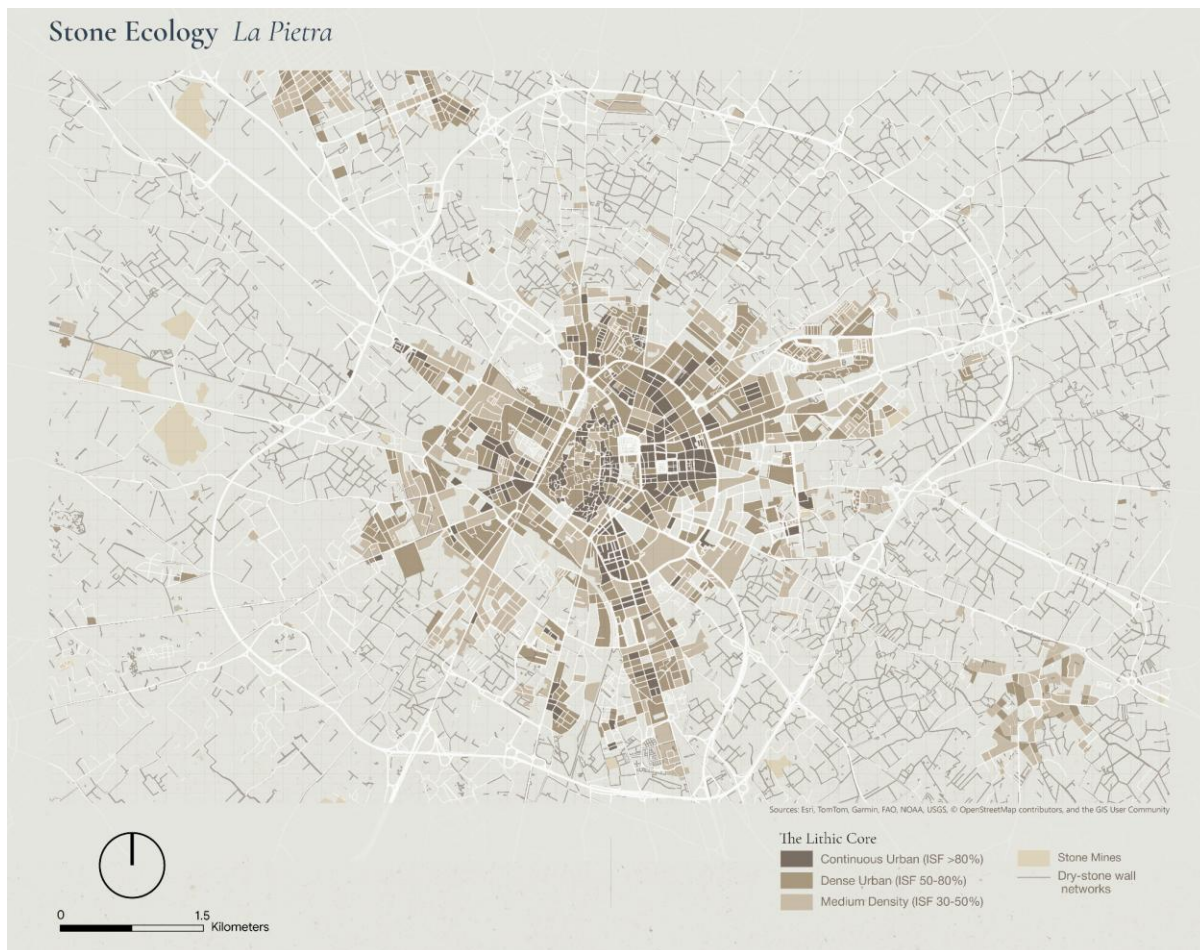
Note.

Distribution of Fire-classified cells. $n = 219$ cells (2.5% of grid). Subclasses F1–F4 in tonal gradation. Cross-validated against CLCbackbone 2023 + Ploughing Indicator 2023 + author-built wall dataset.

Besides the analytical register, the chapter opens two further layers of reading, each at a different degree of interpretive distance from the grid. The first is the individual ecology abstractive map, Figures 7.3d (Stone), 7.3e (Shadow), and 7.3f (Fire); in which each ecology is extracted from the authentic data sources and recomposed onto the territorial substrate as material character rather than classification output. Where the analytical maps show cells positioned across a cadastral grid, the abstractive maps show ecologies as they inhabit and pattern the land. Stone absorbs and holds the city's thermal signature across centuries of lithic continuity, its dry-stone wall network threading the open karst matrix as an agrarian grid that pre-dates the fishnet by five centuries and that the satellite continues to read as the territory's warmest surface in summer precisely because it is the most exposed. Shadow breathes and cools through what remains of the olive canopy and the functional herbaceous mosaic, its surviving patches legible as biological islands under assault, the buffer mechanism still functioning where the landscape has not yet been surrendered. Fire burns and stalls at the edge of a debt cycle that planning has not yet named, its fragmented perimeter tracing the exact geometry of speculative abandonment and incomplete suburbanisation that the cross-validated pipeline makes visible where the Urban Atlas registers only agricultural continuity. These three maps make the claim that morphological

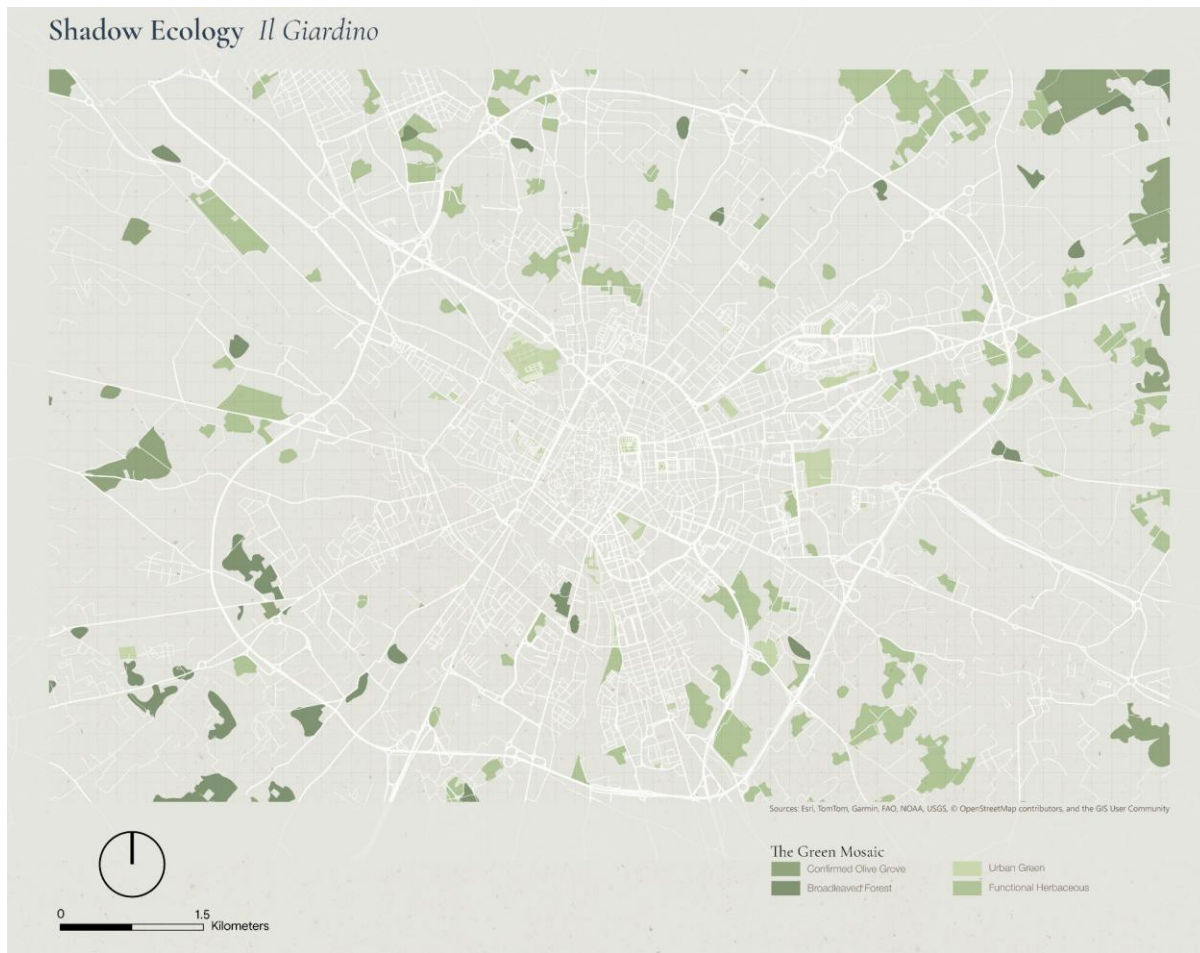
classification is not the end of the reading but its beginning, the point at which spatial evidence becomes spatial argument.

Figure 7.3d Stone Ecology Abstractive Territorial Interpretation



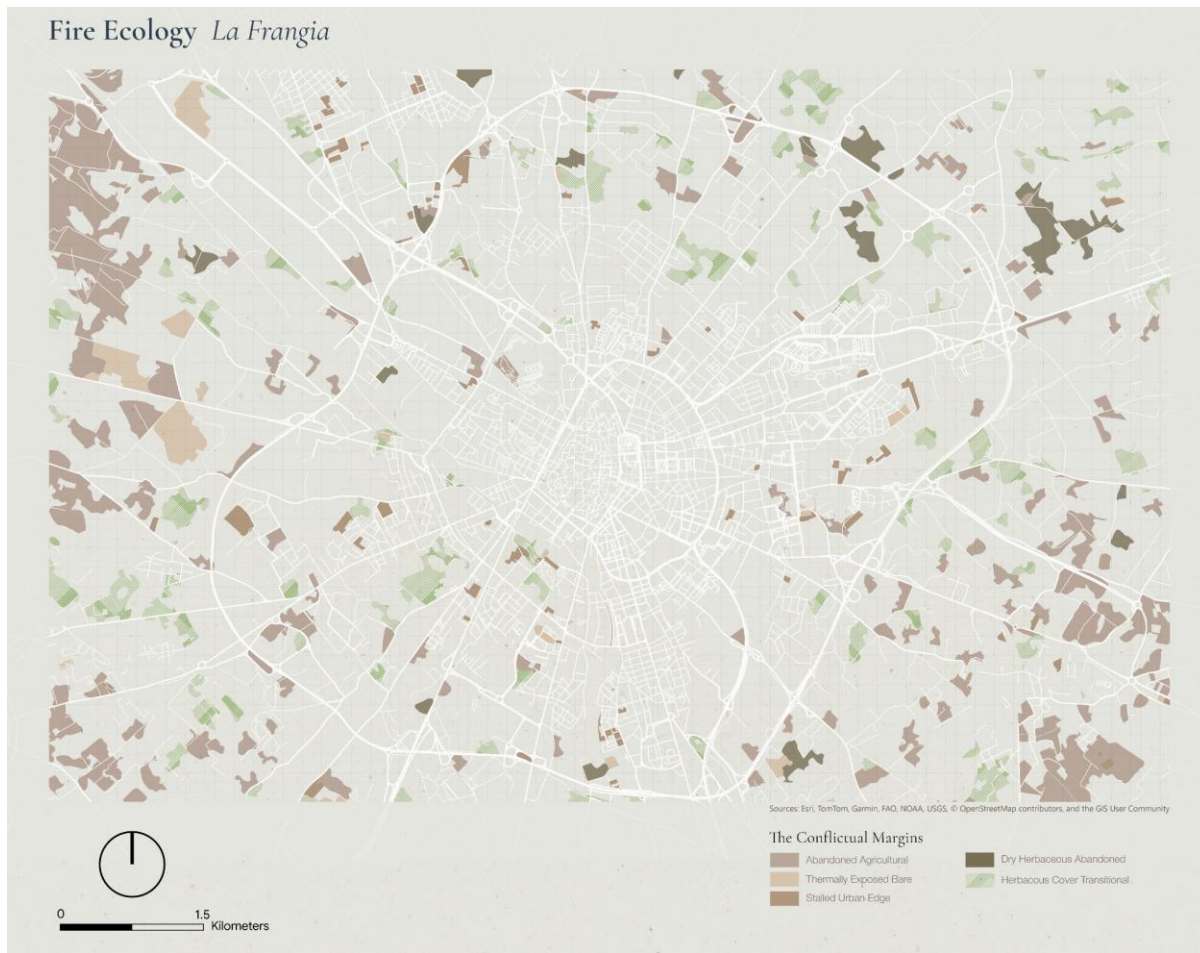
Note. Urban fabric analysis of La Pietra based on Copernicus Land Monitoring Service data. The study area features three density tiers of urban fabric, with the dry-stone wall network (muretti a secco) as the primary cartographic element, outlining agrarian geometry. *Data sources: Urban Atlas Land Cover/Land Use 2021 and author-built muretto a secco vector dataset from Ortofoto AGEA 2019, validated against Regione Puglia SIT data.*

Figure 7.3e Shadow Ecology Abstractive Territorial Interpretation



Note. The Shadow ecology cells, released from the fishnet. The Phase 3.6 refined canopy composite illustrates land use across four subclasses: G1 active olive grove, G2 broadleaved forest, G3 functional herbaceous mosaic, and G4 urban green. Data sources include *Copernicus Land Monitoring Service* and *Urban Atlas Land Cover/Land Use 2021*.

Figure 7.3f Fire Ecology Abstractive Territorial Interpretation



Note. Abandonment analysis of Fire ecology, conflicting margins, utilizing a 247-polygon, 780.64 ha multi-source composite. This composite delineates sub-classes: F1 abandoned agricultural (72.4%), F2 thermally exposed bare karst (9.1%), F3 stalled urban edge (7.5%), and F4 dry herbaceous abandoned (11.0%). Overlaying high-confidence abandonment hotspots (1,268 cells) indicates areas of agreement across independent evidence streams. *Data sources include the Copernicus Land Monitoring Service and associated high-resolution layers.*

The second further reading is the abstractive synthesis presented in Figure 7.3g, in which the three ecologies are no longer held apart but recomposed onto the territorial substrate as a single diagnostic image. What the individual abstractive maps name as distinct metabolisms, the synthesis names as coexistence, the specific friction where Stone ecology presses against Fire at the karst wall's edge, and where Shadow survives in the interstitial spaces that fragmentation has not yet closed. The uni-source classification offered by Urban Atlas 2021 identifies 129.94 hectares of structurally visible Fire ecology; the multi-source cross-validation that the RUTZ pipeline executed revealed 780.64 hectares, the invisible majority that exists within the stable land-use polygons that the European classification reads as agricultural or residential. The Index does not only refine the European classification; it makes legible a fringe condition that the European classification cannot, by construction, see. The synthesis map is, in this sense, not a classification but a diagnosis, and the empirical chapters that follow are the audit that the diagnosis demands. (Figure 7.3g)

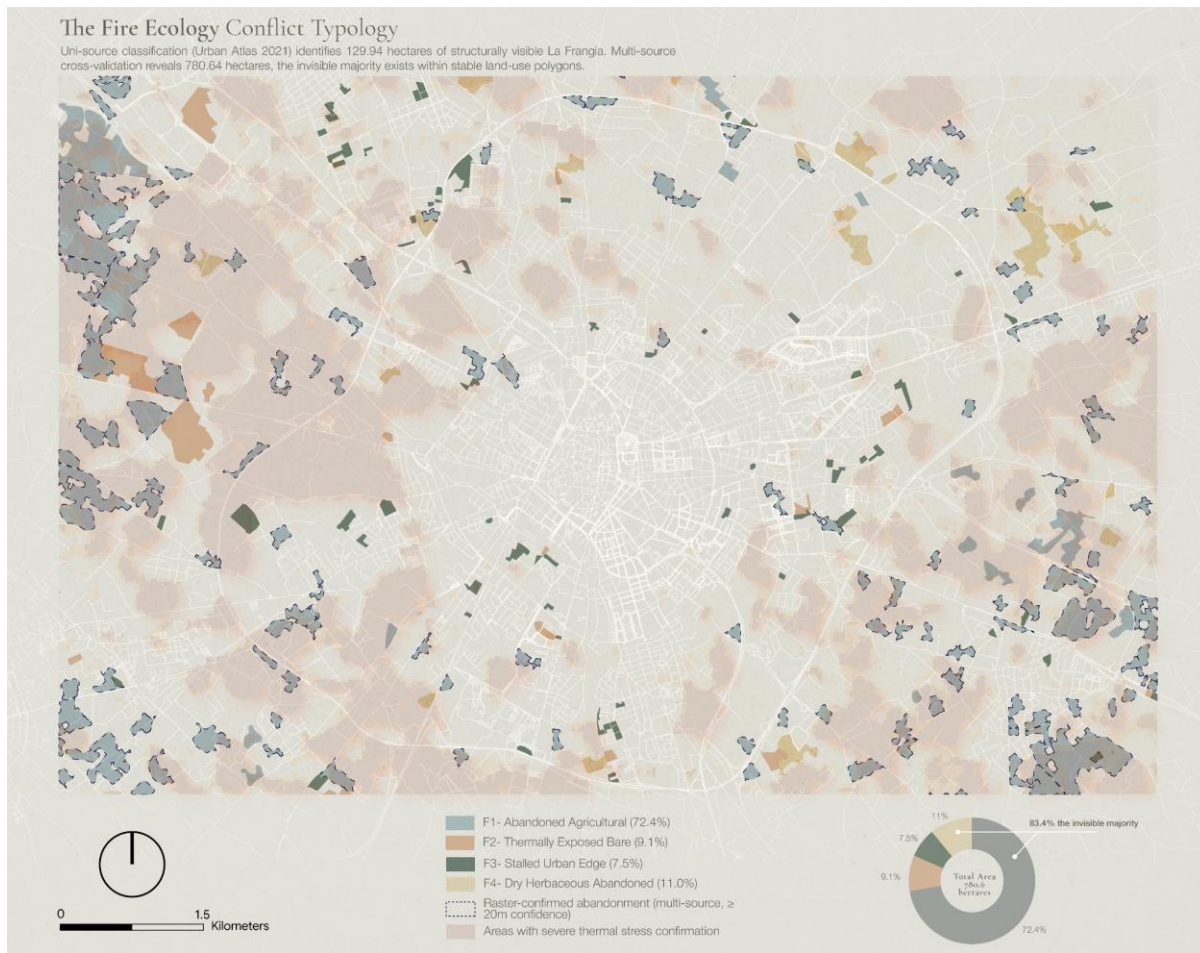
Figure 7.3g Three Ecologies, Territorial Diagnosis (The Synthesis of Ecologies)



Note. Abstractive synthesis map releasing the three ecologies from the fishnet envelope. Urban Atlas 2021 identifies 129.94 ha of structurally visible Fire; multi-source cross-validation reveals 780.64 ha (83.4% invisible). Source: author; Master Profile dominant-ecology field cross-validated against CLCbackbone 2023, Copernicus TCD 2023, and author-built dry-stone wall network.

The diagnostic weight of the classification is most legible in one statistic. The uni-source classification offered by Urban Atlas 2021 identifies 129.94 hectares of structurally visible Fire ecology, the cells where the European reference dataset alone resolves a peri-urban morphology consistent with the conflictual margin. The multi-source cross-validation that the RUTZ pipeline performs (CLCbackbone 2023 raster + Ploughing Indicator + Tree Cover Density + author-built dry-stone wall network) reveals 780.64 hectares, six times that area. The invisible majority exists *within* the stable land-use polygons that the European classification reads as agricultural or residential. The RUTZ Index does not merely refine the European classification; it makes legible a fringe condition that the European classification cannot, by construction, see. Figure 7.3h renders this invisibility as territorial diagnosis: the 780.6-hectare composite, disaggregated into its four constitutive sub-typologies, is overlaid against the summer thermal-stress signal, making legible in a single frame the coincidence that binds the fringe's morphological invisibility to its climatic consequence.

Figure 7.3h The Confictual Territories

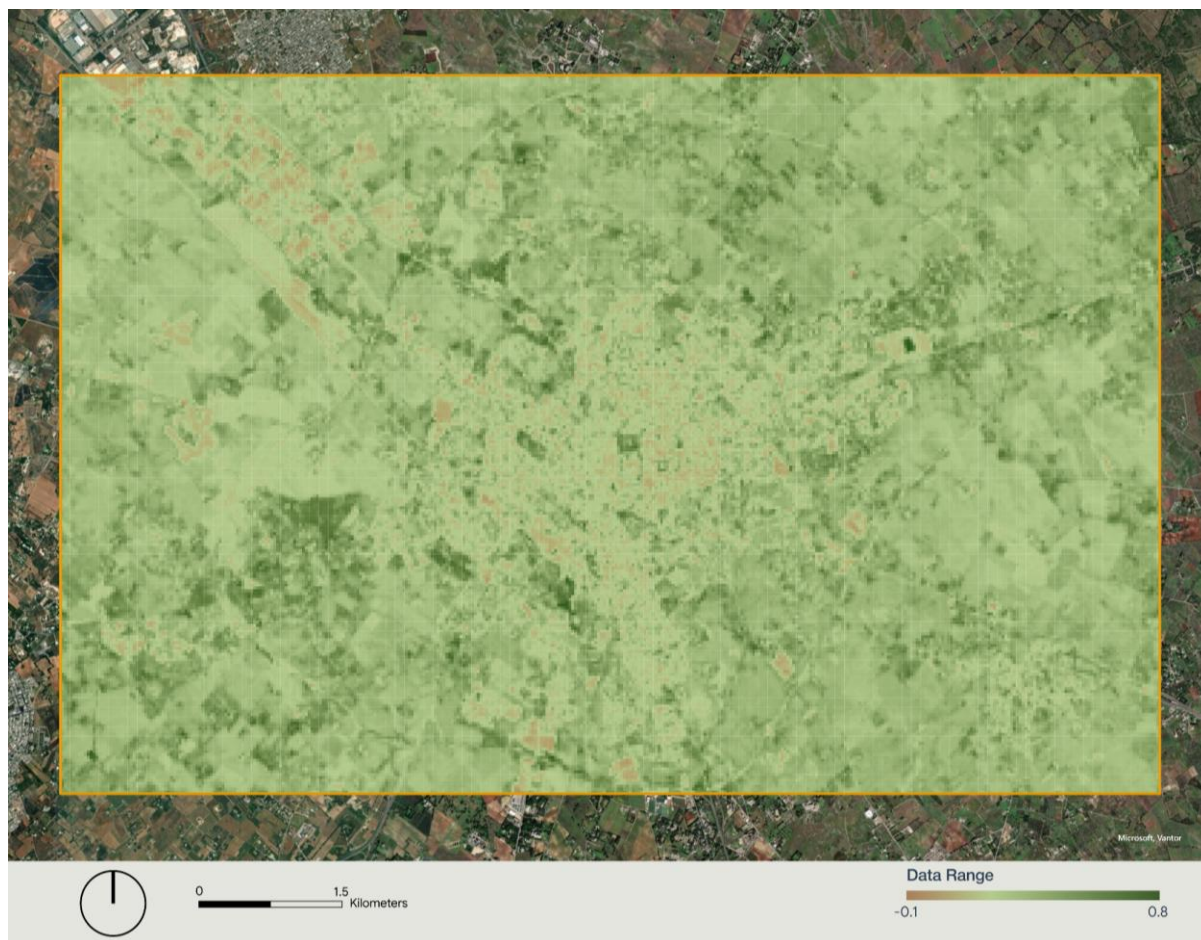


Note. Abstractive interpretive map of the Fire ecology (La Frangia) across the Lecce study area, integrating four constitutive sub-typologies with independent thermal-stress confirmation. *Source. Author's elaboration. Data: Copernicus Land Monitoring Service (2023, 2024); FISHNET Master Profile; FISHNET Thermal TimeSeries; author-built muretto a secco vector dataset.*

7.3 Ecological Cooling Mapping: Vegetation Vitality and the Dry-Summer Decoupling

If the fringe cools itself, it does so through vegetation, and the vegetation record across the seasonal series tells a story that no single summer scene could. In **spring**, the four ecologies are sharply differentiated by greenness: Stone returns the highest mean NDVI of all (0.61), the open karst matrix flushed with herbaceous growth on its winter moisture charge, followed by Shadow (0.51), Transitional (0.41), and Fire (0.31). By **summer**, that ordering has collapsed: every ecology browns, and the spread compresses into a narrow band between 0.27 (Fire) and 0.37 (Shadow), with Stone falling the hardest from 0.61 to 0.35, a loss of 0.26 NDVI units. The summer NDVI surface across the full study grid is mapped in Figure 7.4. The structural canopy baseline that this summer scene draws upon, the territorial distribution of tree cover from which seasonal vegetation dynamics depart, is mapped separately in Figure 7.4a. Figure 7.5 then traces the full seasonal vegetation dynamic, plotting NDVI by ecology across spring, summer, and winter to show how dramatically each ecology's greenness collapses between the two extremes.

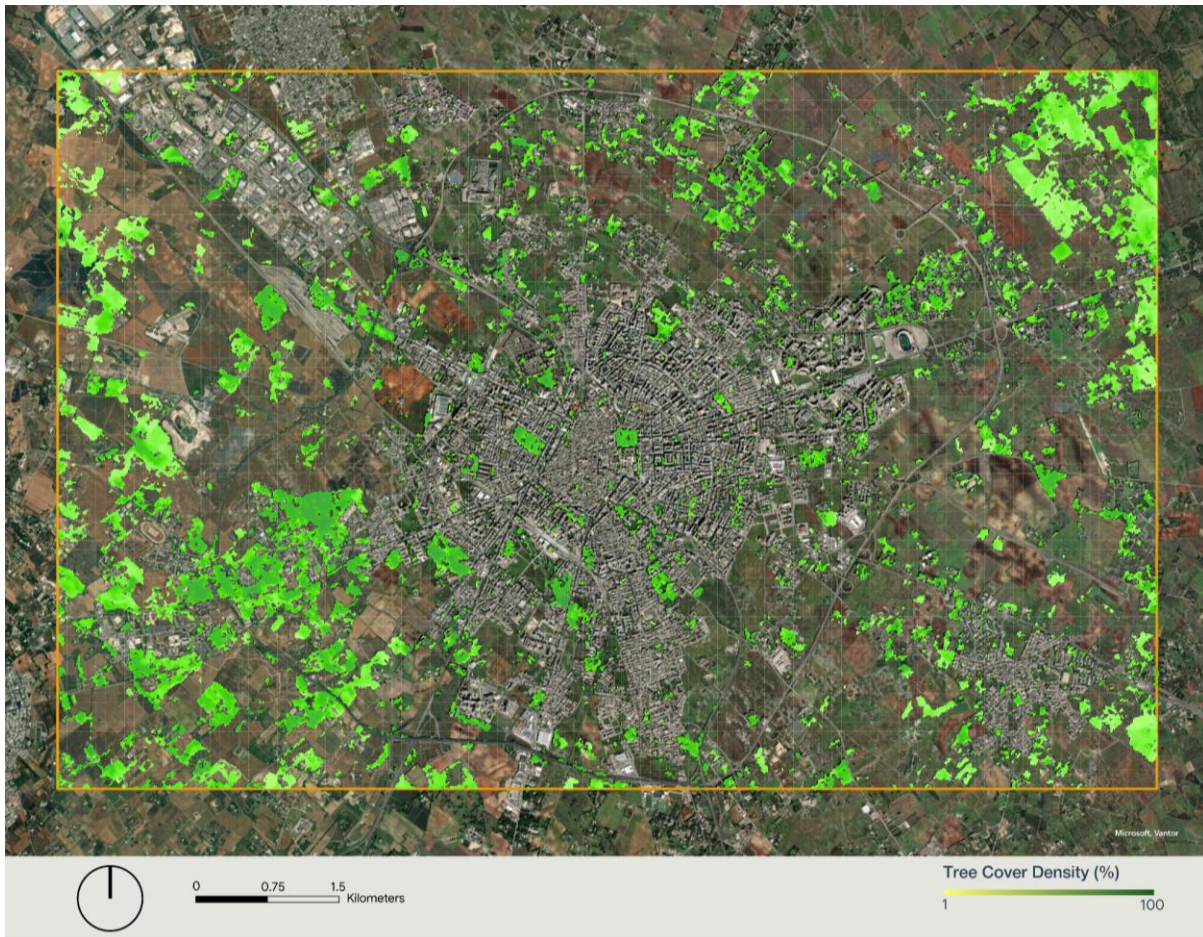
Figure 7.4 Summer NDVI across the Study Area



Note.

Summer NDVI (2025 scene) across the 8,625-cell study area. Sequential ramp symbology. Source: author's analysis; Landsat 8 Collection-2 Level-2, Summer 2025.

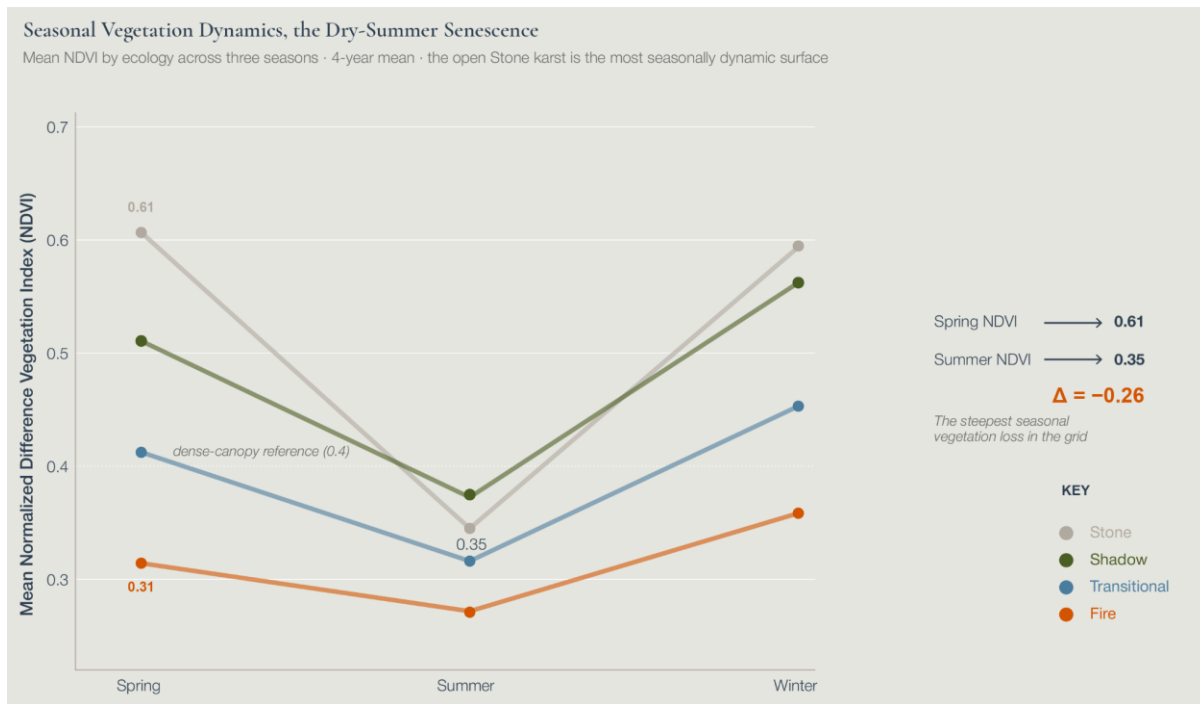
Figure 7.4a Tree Cover Density across the Study Area



Note.

Mean tree cover density (%) per 100-meter fishnet cell, derived from the 2023 Copernicus High Resolution Layer Tree Cover Density raster (10 m, Sentinel-2). The map establishes a baseline for interpreting seasonal NDVI dynamics and summer LST inversions. Continuous canopy is found in scattered shadow ecology patches, while the open stone karst and fire fringe show near-zero canopy. Source: Copernicus Land Monitoring Service (2024).

Figure 7.5 Seasonal Vegetation Dynamics by Ecology



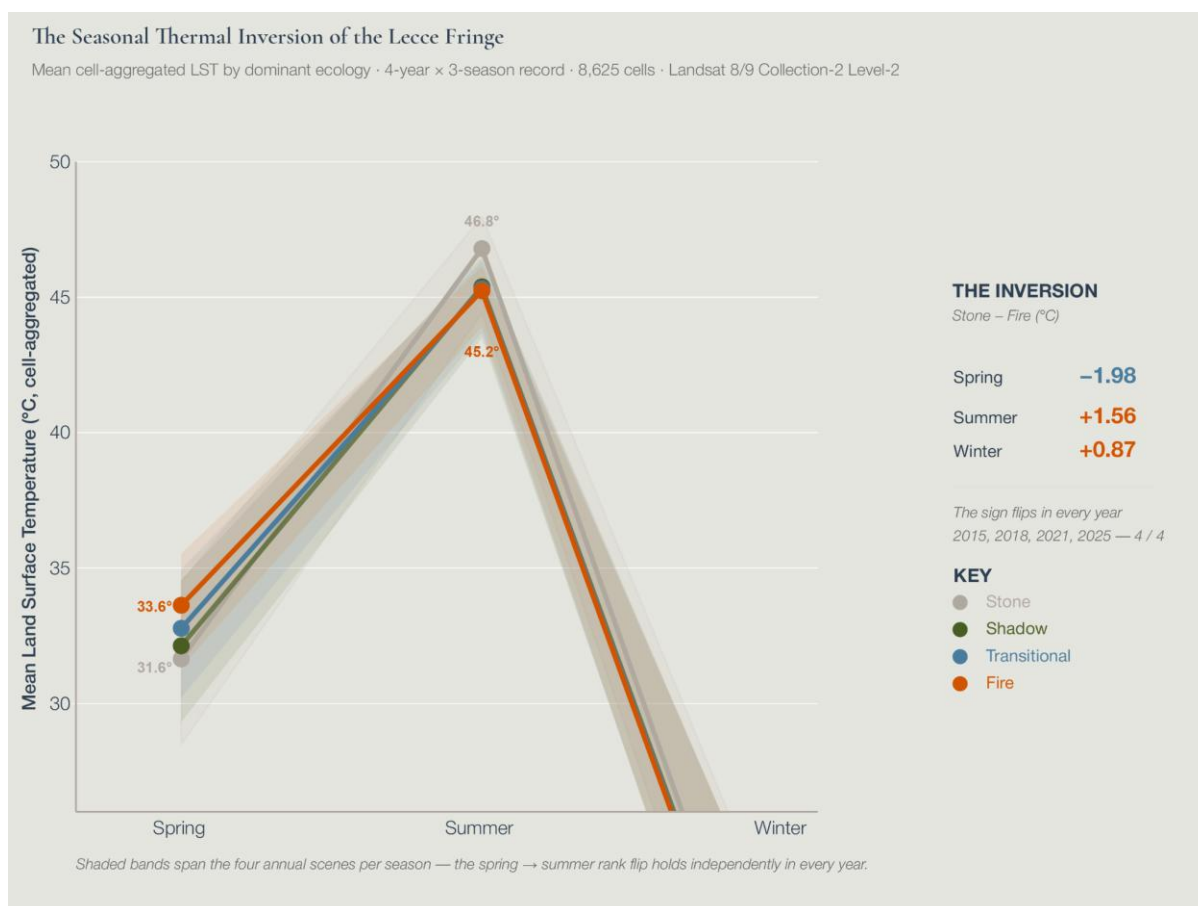
Mean NDVI by dominant ecology across spring, summer, and winter (4-year mean). Stone returns the highest spring NDVI (0.61) and loses the most by summer (0.35), the most seasonally volatile surface in the grid.
Source: Data: Fishnet Thermal Time Series

This collapse is the empirical content of the Mediterranean dry-summer decoupling that Chapter 5 first surfaced as a weak, negative summer vegetation-temperature correlation. The grass and the herbaceous understory of the karst are technically present in July but physiologically dormant, browned, no longer transpiring, no longer cooling. Greenness, in this climate and this season, stops being an engine for cooling capacity. The consequence is methodological as much as ecological: a buffer argument built on NDVI alone would read the summer fringe as uniformly stressed and miss the structure entirely. It is the moisture indices, not the vegetation index, that carry the cooling signal in summer, a point section 7.7 makes quantitative and section 7.5 makes spatial: the transect profile in Figure 7.10 renders the same decoupling as a continuous section, with the summer NDMI collapse and the LST peak appearing in mirrored sequence along the gradient.

7.4 The Thermal Signature: Land Surface Temperature and the Seasonal Inversion

The central finding of this thesis can be stated in a single sentence: the thermal ranking of the Lecce ecologies inverts between spring and summer, and the inversion holds in every year of the record. Figure 7.6 is the evidence.

Figure 7.6 The Seasonal Thermal Inversion



Note. Mean Land Surface Temperature by dominant ecology across spring, summer, and winter, 4-year record (2015, 2018, 2021, 2025). Shaded bands span the four annual scenes. Spring: Fire hottest (33.6°C), Stone coolest (31.6°C). Summer: Stone hottest (46.8°C), Fire coolest (45.2°C). The sign reversal holds in all four years. Source: author's analysis; Landsat 8/9 Collection-2 Level-2.

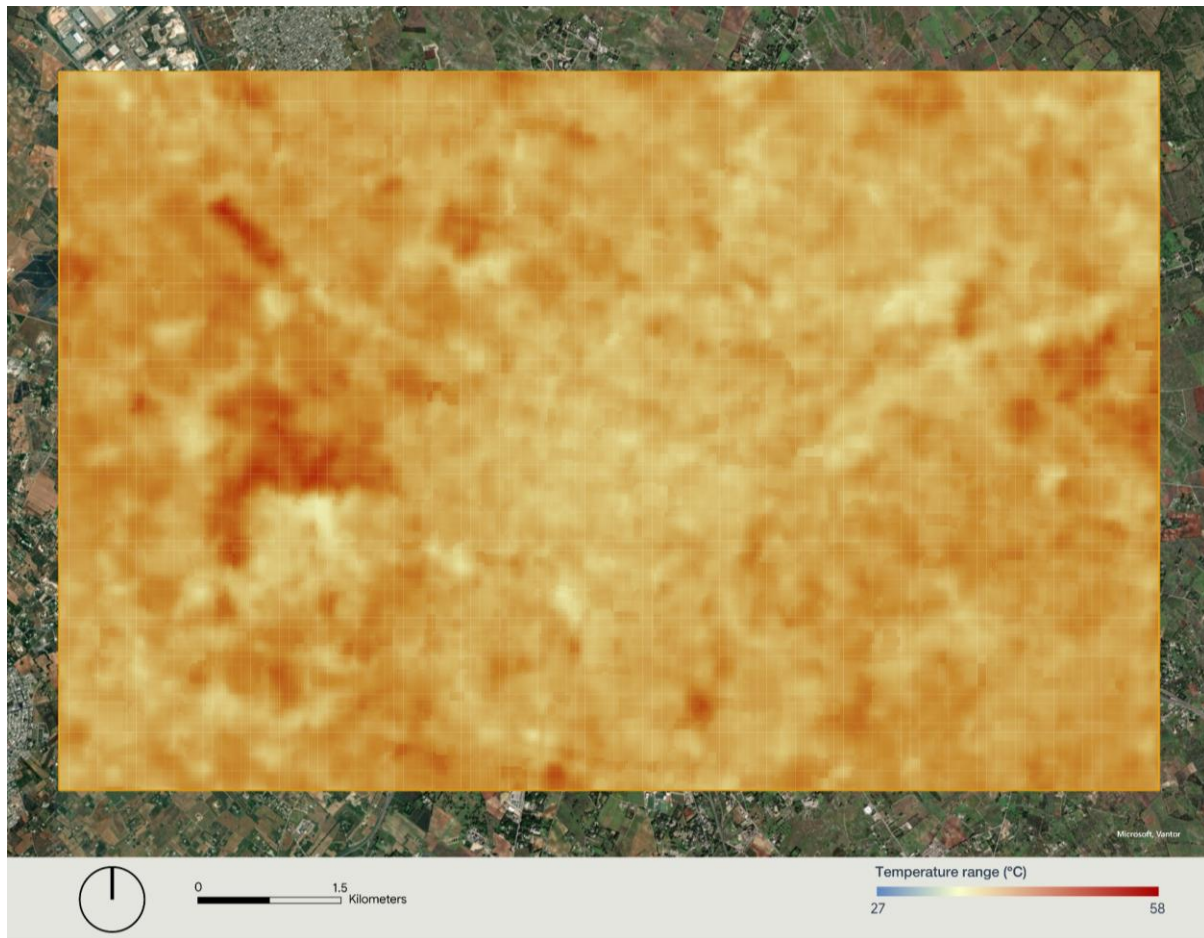
In **spring**, the ordering is canonical: the built, sealed Fire fringe is the hottest ecology (mean 33.6°C), and the open Stone karst is the coolest (31.6°C), a Stone-minus-Fire gap of –2.0°C consistent with ordinary sealed-versus-open thermal theory. In **summer**, the ranking flips: Stone becomes the hottest ecology in the study area (46.8°C), Fire the coolest (45.2°C), a Stone-minus-Fire gap of +1.6°C. The sign of that gap reverses between spring and summer in four years out of four, 2015, 2018, 2021, and 2025 alike, which is why the shaded annual bands in Figure 7.6 never overturn the pattern. This is not a single-scene artefact; it is a structural, repeating seasonal behaviour.

Winter resolves the picture rather than complicating it. In the cool season, the summer ranking is preserved but muted: Stone ecology zones remain marginally the hottest (15.6°C against Fire's 14.7°C), which confirms that the spring condition, not the summer one, is the true outlier: spring is the one season in which the open karst, freshly recharged with winter moisture, out-cools the built and unbuilt fringe. Across the seasons, Stone ecology is also the most thermally volatile one, swinging 15.1°C between spring and summer against Fire's 11.6°C. The open karst is a thermal switch; the built fringe is a thermal flywheel.

The summer field, read on its own, is a textbook reverse urban heat island resolved at the hectare scale of the study. Stone is the only ecology whose surface temperature sits above

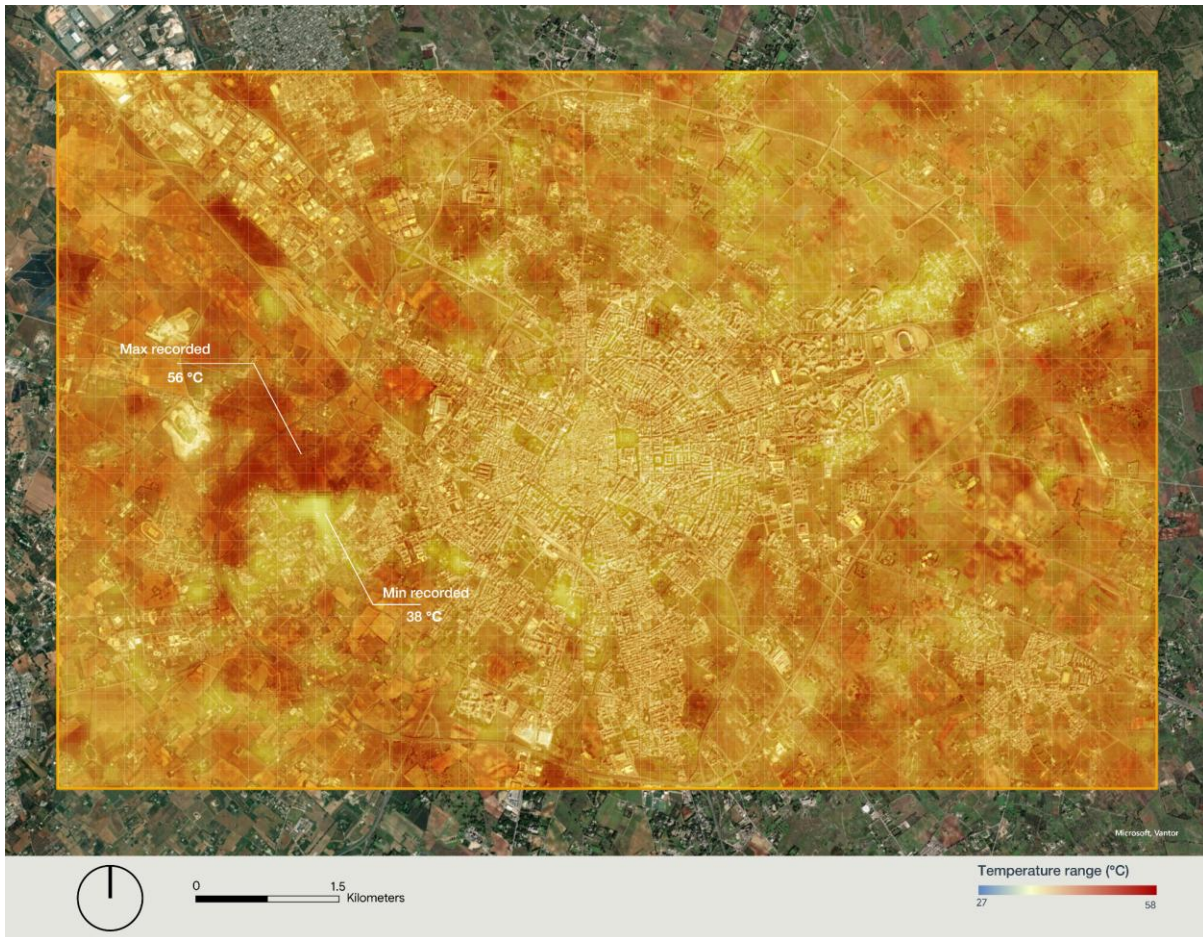
the scene mean (summer SUHI anomaly $+0.41^{\circ}\text{C}$; all others negative), and the thermal-stress index confirms the pattern categorically: Figure 7.7 maps this gradient spatially across the full grid. Along the two thermal maps, another supplementary map was added with a high graphical hard light visualization technique to pinpoint and observe the clusters of extreme and moderate zones. (Figure 7.7a)

Figure 7.7 Summer LST across the Study Area



Note. Summer LST (2025 scene) across the 8,625-cell study area. Color ramp fixed across all four summer scenes (2015, 2018, 2021, 2025) for cross-date comparability: stretch range $27\text{--}58^{\circ}\text{C}$, set with a margin beyond the empirical four-year summer extremes of 28.49°C (Summer 2021 minimum) and 56.50°C (Summer 2015 maximum). Source: author's analysis; FISHNET Thermal TimeSeries; Landsat 8 Collection-2 Level-2.

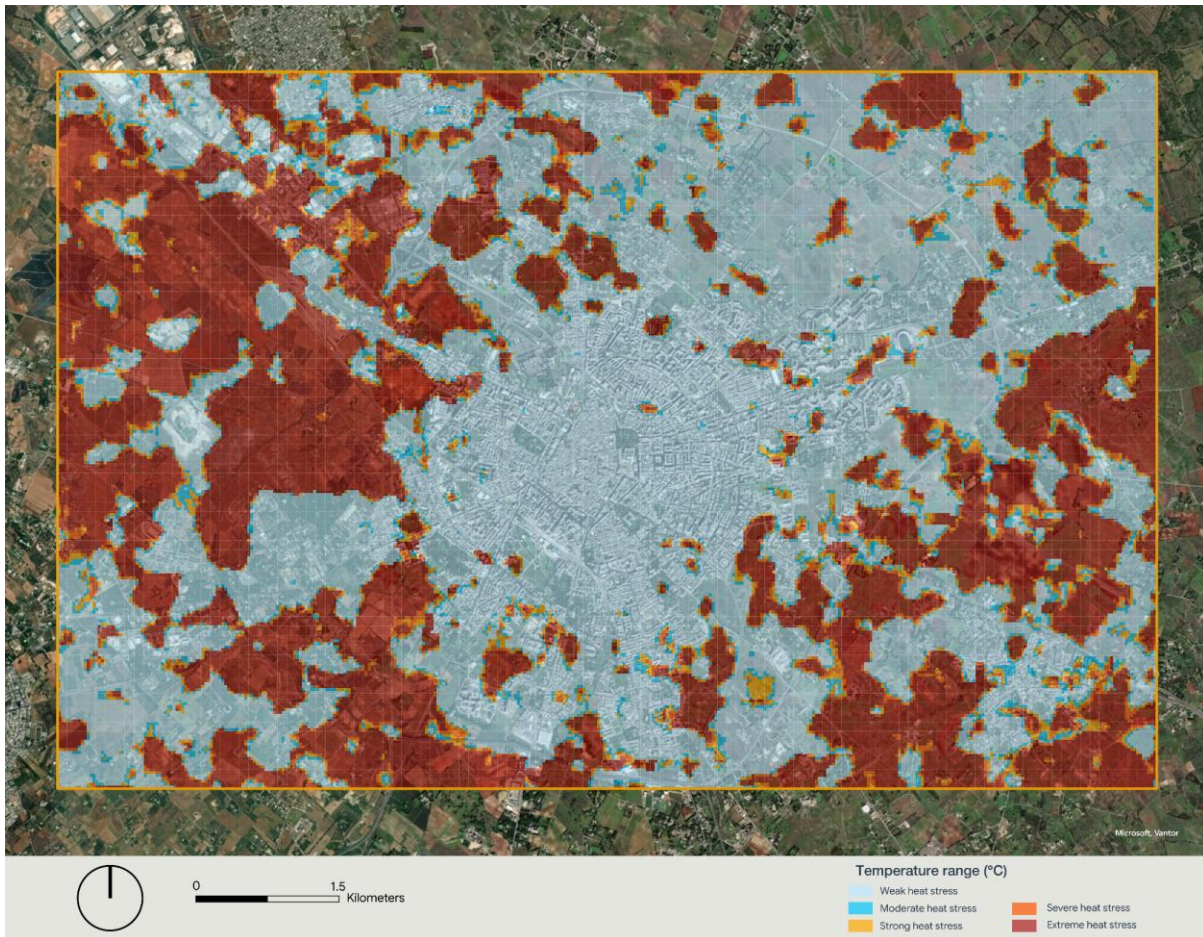
Figure 7.7a Overlaid LST graphical enhancement on the study area



Note. Summer LST (2025 scene) across the study area with the hard light overlay graphics for observation of extreme thermal zones.

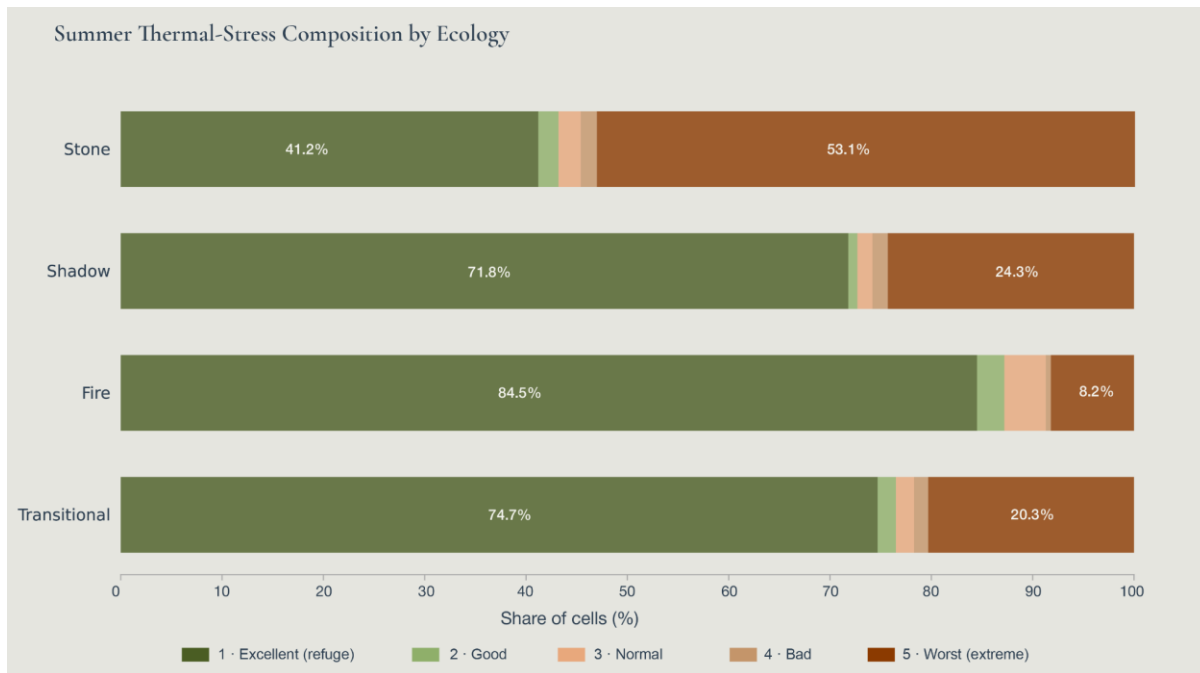
It should be mentioned that in the thermal stress classification (Figure 7.9), Stone carries 53% of its cells in the worst class, while the built Fire fringe places 85% of its cells in the best refuge class. Along the peri-urban gradient, the same inversion appears as a monotonic trend, and mean summer LST falls from 46.92°C in the deep Rural Matrix to 45.56°C in the Critical Fringe, a 1.4°C decline as the cells become more peri-urban. In high summer, the territory grows hotter as it grows more rural and open, not as it grows more built. Aside from land surface temperature mapping in peak summer temperatures, the thermal-stress categories that LST facilitates its mapping is therefore in Figure 7.8. Five distinct classes that help us to better understand the zones that are thermally intolerable.

Figure 7.8 Summer UTFVI Thermal-Stress Class



Note. Six-class UTFVI thermal-stress classification (Summer 2025). Source: author's analysis after Liu & Zhang (2011); Landsat 8 Collection-2 Level-2.

Figure 7.9 Summer UTFVI Composition by Ecology

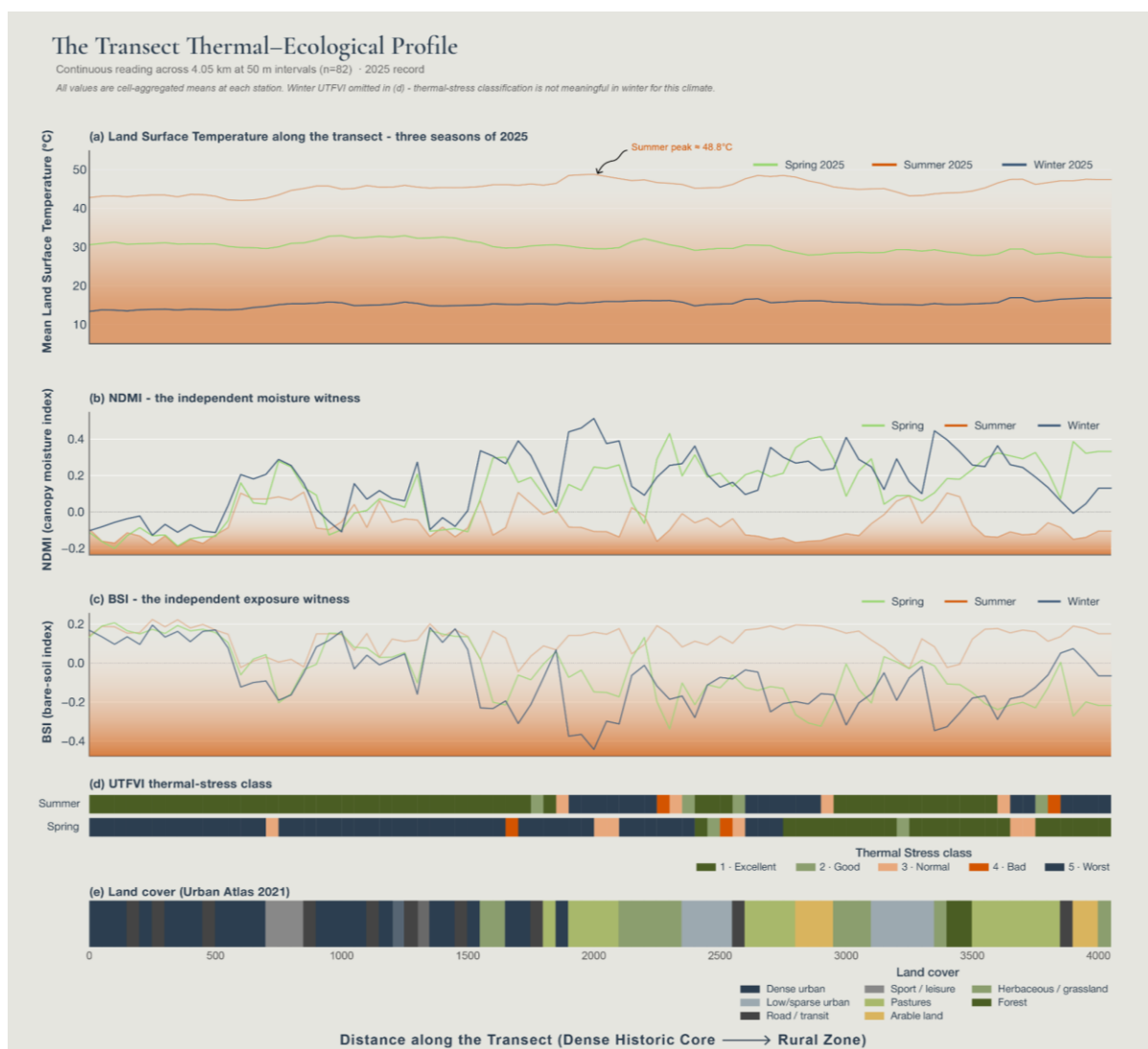


Note. Share of cells by UTFVI thermal-stress class within each dominant ecology, Summer 2025. *Source:* FISHNET Thermal Time Series; ecology classification by FISHNET Master Profile.

7.5 The Transect: Reading the Inversion as a Continuous Section

What the cell statistics establish as a population pattern, the transect renders as a continuous spatial argument, a single 4.05-kilometre section sampled at 50-metre intervals, from the dense historic core, across the Tangenziale ring, through the contested peri-urban edge, and into the agricultural matrix beyond. Figure 7.10 is the section. Its five stacked panels, LST across three seasons, the independent moisture witness (NDMI), the independent bare soil exposure witness (BSI), the UTFVI thermal-stress class strip, and the land-cover ribbon below, let every thermal inflection along the line be named by the ecology and the cover type that produces it.

Figure 7.10 Transect Thermal–Ecological Profile (5 panels)



Note. Continuous reading across 4.05 km at 50 m intervals (n = 82 data points). *Source: author's analysis; Landsat 8/9 Collection-2 Level-2; Urban Atlas 2021.*

The continuous LST profile in Panel (a) shows the inversion as a spatial rather than a categorical fact. In summer, surface temperature rises steeply from the dense urban core, peaks at approximately 48.9°C around the 2,000-metre station, squarely in the open agricultural pasture and herbaceous-grassland zone outside the ring road, and remains elevated through the rural terminus. In spring, the same profile is essentially the inverse: the urban end of the section is warm, and the rural matrix at the transect's far end is cool, exactly as the cell-level statistics in section 7.4 would predict. Winter compresses the gradient to within four or five degrees and reproduces the muted summer ordering.

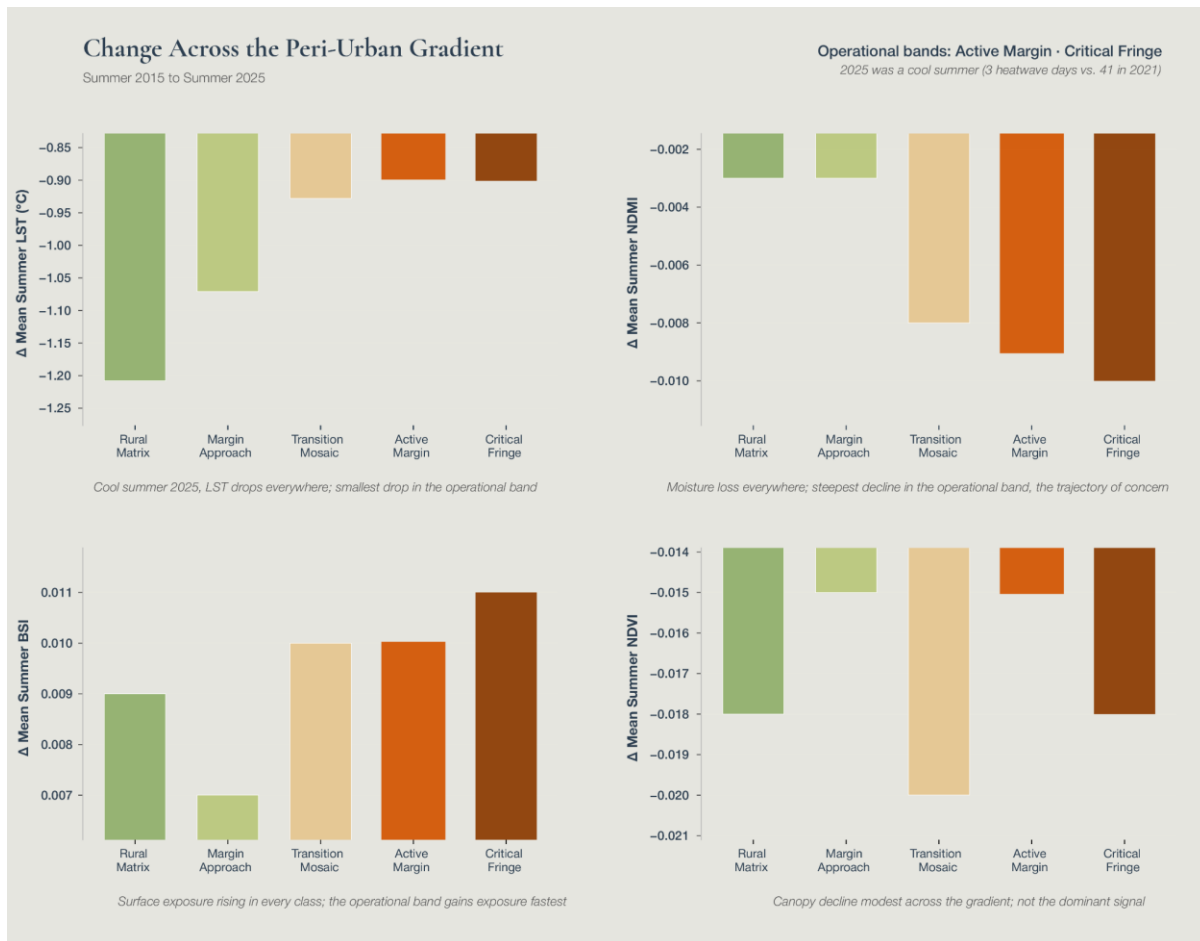
The two independent moisture and exposure panels confirm the mechanism along the section. NDMI in Panel (b) collapses from positive values in the dense, partially shaded urban segments toward zero and below as the line crosses into the open pasture and karst matrix in summer, while remaining strongly positive across the entire profile in spring, the same canopy-moisture loss that the cell-level analysis identified as Stone's seasonal collapse. BSI

in Panel (c) does the opposite, rising into the open agricultural terrain precisely where NDMI falls, marking the bare-soil exposure that the cell-level correlation analysis isolated as the thermal driver. The UTFVI class strip in Panel (d) registers the consequence: in summer, the urban segment reads as predominantly Class 1 (refuge), and the rural-terminus segment as Class 5 (worst); in spring, the classes invert station for station. Two interpretive disciplines govern the reading. First, every value is the cell-aggregated mean at each station, not a single-pixel measurement. Second, the soil-moisture and dryness indices are within-scene relative measures; the spring-to-summer comparison reads the reshuffling of relative positions, not an absolute volume of water lost.

7.6 Change in the Operational Peri-Urban Band – the Intervention Zones

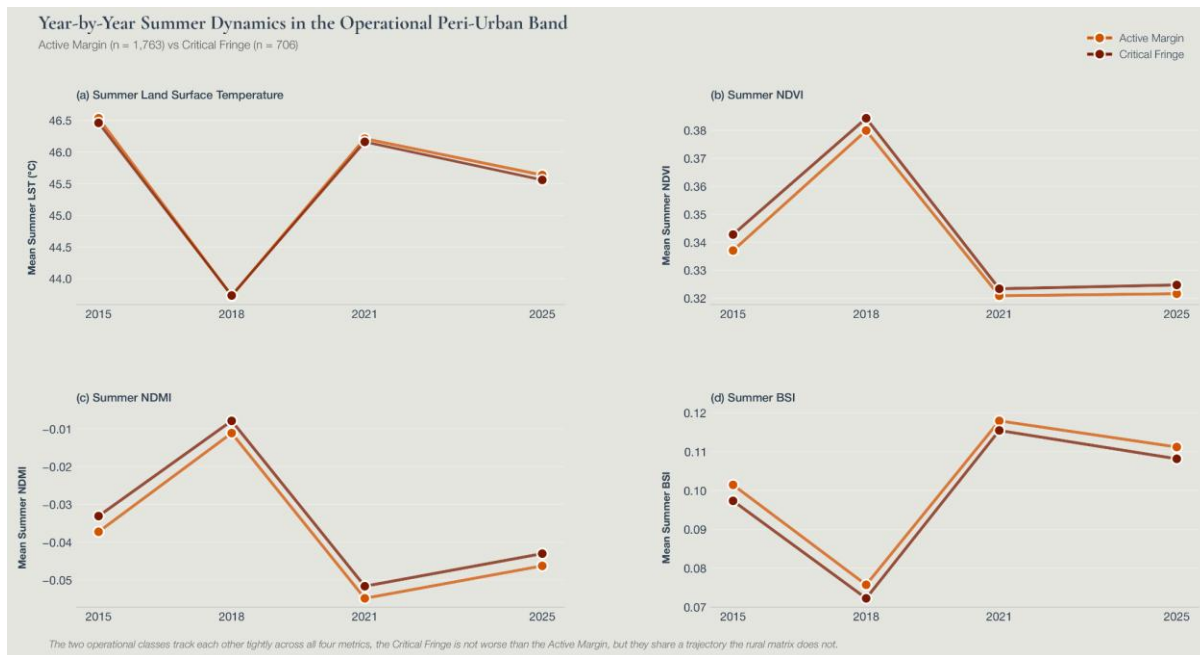
The seasonal inversion describes the territory's behaviour at any one moment in time. The *change* of the peri-urban band between 2015 and 2025 describes its trajectory — and that trajectory is the empirical justification for treating the Active Margin (1,763 cells) and the Critical Fringe (706 cells) as the operational peri-urban zone where intervention is warranted. Figure 7.11 presents the same sensor from 2015 to 2025, compared across the gradient, and Figure 7.12 shows the operational band itself across four sequential summers.

Figure 7.11 Change across the Peri-Urban Gradient (Summer 2015 to 2025)



Note. Same-sensor Landsat 8 → Landsat 8 comparison of mean summer LST, NDMI, BSI, and NDVI across the five peri-urban classes. Active Margin and Critical Fringe are the only classes where summer SMI declines while BSI rises. *Source: author's analysis; FISHNET Thermal Time Series dataset*

Figure 7.12 Year-by-Year Summer Dynamics in the Operational Bands



Note. Active Margin (n = 1,763) vs Critical Fringe (n = 706) across four summer Landsat 8 scenes (2015, 2018, 2021, 2025). Four panels: summer LST, NDVI, NDMI, BSI. The two operational classes track each other tightly; they share a trajectory that the rural matrix does not. Source: author's analysis; FISHNET Thermal Time Series dataset.

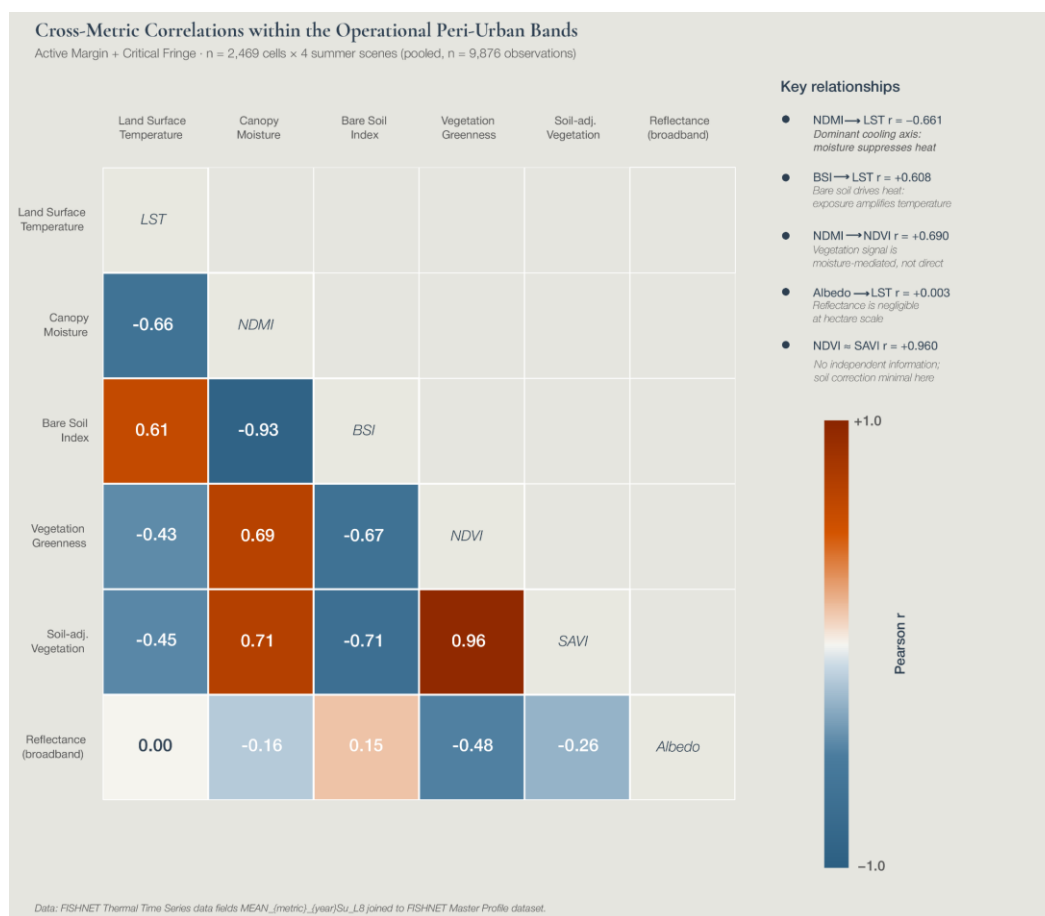
Three features of the comparison matter for planning. First, summer LST falls between 2015 and 2025 in every peri-urban class, a uniform -1°C shift driven by scene-acquisition conditions, not a decadal cooling, and the chapter therefore reads the four-year record as a replication of the inversion rather than as a warming trajectory. Second, NDVI declines slightly across all classes, and BSI rises across all classes, but the changes run with the same gradient direction across the territory; they do not pick out the peri-urban band as a distinct trajectory in isolation. Third, and this is the planning signal and highly noticeable, the soil-moisture index moves in opposite directions across the gradient: the Rural Matrix gains relative moisture ($\Delta +0.013$), the Margin Approach is essentially flat, and the Active Margin and Critical Fringe are the only classes where the index *declines* ($\Delta -0.003$ in both). Coupled with the steeper NDMI decline in the same two classes ($\Delta -0.009$ and -0.010 against -0.003 in the rural matrix), this is the signature of a peri-urban band that is moisture-losing while the deep rural matrix is moisture-gaining.

The year-by-year reading in Figure 7.12 sharpens the point. Across the four summer scenes, the two operational classes track each other tightly across all four metrics, LST, NDVI, NDMI, BSI, and they share a trajectory that the rural matrix does not. The Critical Fringe is not worse than the Active Margin; the two are partners in a single trajectory, separated only by intensity. Inter-annual variability is substantial, 2015 reads warmer and drier than 2018 and 2025 by approximately 1°C , but the seasonal inversion holds and the operational-band signature persists in every year.

Why this matters analytically becomes legible when the cross-metric correlations within the operational band are read explicitly, as in Figure 7.13. Within the pooled Active Margin and

Critical Fringe cells across the four summers, the NDMI–LST relationship returns the strongest independent negative correlation (mean $r \approx -0.70$), confirming canopy moisture as the dominant cooling axis even at this restricted analytical scope. NDVI–NDMI returns the strongest internal coupling among the spectral indices ($r \approx +0.85$), evidence that the vegetation signal is moisture-mediated rather than independent of it. BSI–NDMI, on the other hand, is strongly negative ($r \approx -0.75$), confirming that bare-soil exposure in the operational band reads as the inverse face of canopy-moisture loss. The within-band picture is therefore exactly what one would predict from the larger-grid mechanism: the same moisture-driven dynamic that produced the seasonal inversion at the whole-territory scale operates *within* the operational band as the law motion of its summer behaviour.

Figure 7.13 Cross-Metric Correlations within Peri-urban bands



Note. Active Margin and Critical Fringe cells pooled, cell-wise Pearson correlations between summer indices across four scenes. Source: author's analysis; FISHNET Thermal Time Series dataset

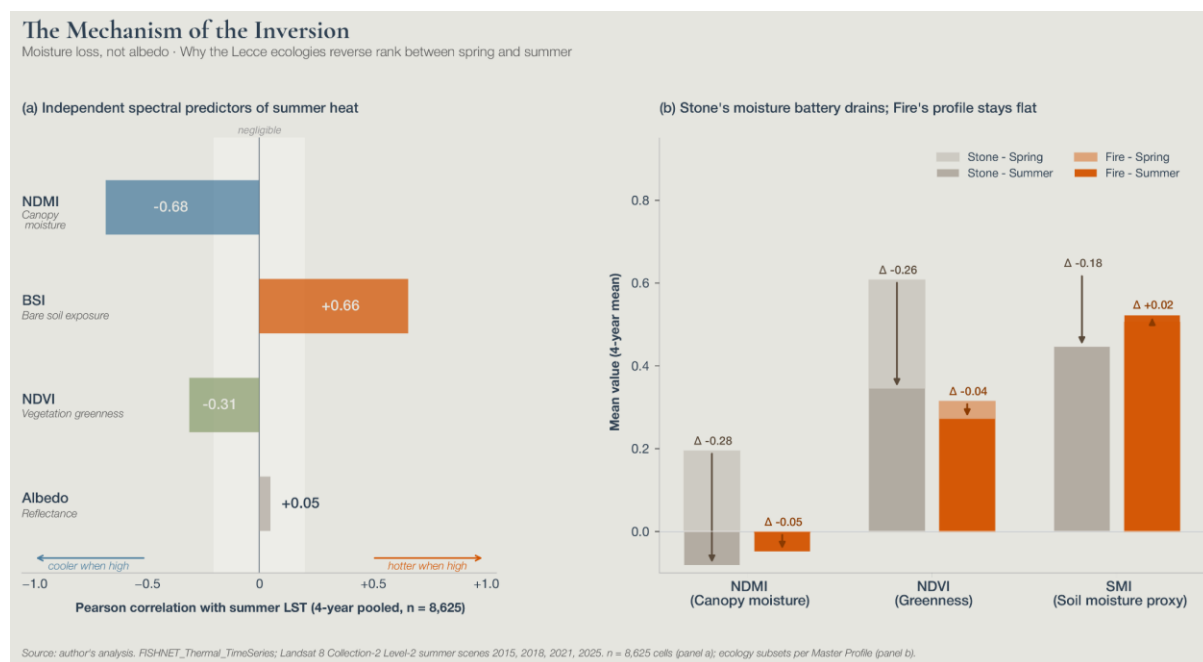
The planning consequence is that the operational peri-urban band is not simply hotter than the deep rural matrix; in summer 2025,

it is, in fact, cooler than it (Critical Fringe 45.56 °C against Rural Matrix 46.92 °C), confirming the reverse-UHI gradient described in section 7.4. But it is the only segment of the gradient where the moisture indicators are deteriorating, and that deterioration is the early-warning signal that the buffer's mechanism, the spring moisture reserve that drives evaporative cooling, is being eroded precisely where the planning instruments still have leverage. The Active Margin and Critical Fringe are the intervention zones not because they carry the highest absolute summer temperature, but because they carry the trajectory the rural matrix does not yet share.

7.7 Bivariate Correlation: The Mechanism of the Inversion

Why does the open karst, coolest in spring, become the hottest surface in summer? The mechanism is moisture, and the seasonal indices isolate it cleanly. Stone holds the highest relative soil moisture of any ecology in spring and the lowest in summer; what it means is that the soil-moisture index falls from 0.62 to 0.45 across the two seasons, by far the steepest seasonal decline in the whole grid, while the built Fire fringe barely. The same collapse is visible in the independent canopy-moisture index, which falls for Stone from +0.19 in spring to -0.08 in summer, again the steepest drop of all ecologies. The karst behaves as a moisture battery: charged by winter rain, it keeps evaporative cooling through spring, and once that shallow reserve is exhausted under the Csa drought climate regime, the bare limestone substrate is left to absorb and re-radiate the summer sun with no biological mechanism to intercept it. Figure 7.14 reads this mechanism directly.

Figure 7.14 *The Mechanism of the Inversion: Moisture Loss, Not Albedo*



Note. (a) Independent spectral predictors of summer LST across the grid. Source: author's analysis; FISHNET Thermal Time Series dataset

The correlation structure confirms that the driver is moisture and exposure, not reflectance. Across the grid, summer LST correlates -0.67 with the canopy-moisture index and +0.59 with the bare-soil index, strong, independent spectral relationships, while its correlation with surface albedo is negligible (-0.06). At the scale of the fringe and the resolution of this analysis, the inversion is an evapotranspiration story, not an albedo one: the limestone's reflectivity, decisive at the scale of a single historic facade, does not govern the thermal

ranking of hectare-scale ecologies. A necessary methodological note accompanies this reading: the soil-moisture and temperature-dryness indices, being within-scene rescalings of LST, correlate with it at -1.00 by construction and are therefore treated as re-expressions of the thermal signal rather than independent confirmations of it. The canopy-moisture and bare-soil indices, derived from reflectance bands, are the independent witnesses, and it is on their evidence that the moisture mechanism rests.

This same multi-index discipline resolves the apparent paradox of wall density, which correlates *positively* with summer LST ($+0.21$) across the grid. Walls do not heat the territory; they mark the Stone matrix, and the Stone matrix bakes in summer. The correlation is compositional, a reminder that at the scale of the whole grid the ecologies act as confounders, and that the genuine drivers emerge only when the relationships are read within ecologies as well as across them. Read within Stone alone, vegetation reasserts its expected cooling role, summer LST correlates -0.45 with NDVI inside the Stone matrix, against a near-zero relationship with built fraction. The heat of the open karst is the heat of bare, moisture-exhausted ground, and the surviving vegetation within it still cools, exactly as theory predicts, once the confounding of ecology against ecology is removed.

7.8 Deep Learning Feature Extraction: Canopy Recovery and the Limestone Lesson

The canopy layer that underwrites the Shadow/Canopy ecology was recovered from the 0.5-metre orthophoto by deep learning, and the result is reported here with the limitation that shaped it. As Chapter 5 documented, the initial object-level tree-detection model systematically mistook bare Pietra Leccese white surfaces, limestone walls, unpaved courtyards, and exposed karst outcrops for olive crowns, because in the visible spectrum the luminous stone and the grey-green canopy occupy overlapping reflectance regions. The very material that gives the Salento its cooling albedo deceived the algorithm built to count its trees. The resolution was a pivot from instance-level detection to pixel-based land-cover classification reconciled against the Copernicus Tree Cover Density 2023 dataset reference, trading per-tree counts for a defensible canopy fraction. The limestone-false-positive evidence is documented in Figure 5.5 (section 5.5), where the orthophoto crop illustrates the spectral confusion between bare Pietra Leccese and sparse canopy that the deep-learning model produced under the standard confidence threshold.

The lesson generalizes beyond a software detail. Spectral and object-detection models calibrated for temperate or tropical landscapes carry an implicit assumption that bright surfaces are built or vegetated, not bare stone, which fails in a limestone karst setting. Any canopy-detection workflow transferred to a Pietra Leccese context must include an explicit reconciliation against an independent reference, or it will systematically over-count green where there is only stone.

7.9 Synthesis: What the Grid Has Shown

The chapter set out to ask whether a slow morphological identity could predict a fast thermal behavior, and whether that behavior carried a directional signal across the decade of available record. The answers are, in order, yes and partially. The four ecologies, classified without any thermal input, separate coherently in a thermal record they were never built from, and they do so in a season-dependent structure that a static classification could not have anticipated, the inversion of section 7.4. The decadal record shows no warming trajectory at the resolution of the fishnet, but it does show that the operational peri-urban band carries a moisture-losing signature that the deep rural matrix does not; the change finding of section 7.6, sharpened by the year-by-year reading and the cross-metric correlations within the band. The combination locates the planning argument that the rest of the thesis advances. The buffer is not a fixed property of land cover; it is a seasonally contingent performance whose mechanism (moisture, not reflectance) is being eroded in precisely the cells where intervention can still act. The Active Margin and the Critical Fringe are those cells. The RUTZ Index, calibrated in Chapter 9, is the instrument that measures their state; Chapter 10 reads what should be done about them.

Chapter 8

CHAPTER 8: Socio-Demographic Vulnerability & the Heat Mosaic

The morphological and thermal analysis of Chapters 6 and 7 has identified where the fringe burns. Chapter 8 asks who lives inside the burn. The Heat Risk Index constructed in this chapter does not replace the RUTZ spatial reading; it extends it into the register of bodies: which census sections carry the convergence of maximum thermal exposure, minimum cooling canopy, and maximum population concentration that defines genuine heatwave risk. The result is not a repeat of the Chapter 7 argument at a different resolution. It is its human consequence, made legible at the scale of the street and the neighborhood.

8.1 The Weather-Station Network: ARPA Puglia and Landsat Cross-Comparison

The remote-sensing record that forms the thermal backbone of this thesis operates at a spatial resolution the network of ground-based weather stations cannot match. Landsat imagery at 30-meter pixel resolution resolves the thermal heterogeneity of individual parcels, the temperature difference between a sealed driveway and the surviving olive canopy ten meters away. A weather station records air temperature at a single point, blending the thermal signal of the surrounding fabric into a single hourly value. The two instruments do not compete; they triangulate. What the Landsat record shows spatially, the weather station network confirms temporally and in absolute air-temperature terms.

The ARPA Puglia monitoring network in Lecce has been the subject of four years of systematic analysis by Pappaccogli et al. (2024, 2025), who compare Urban Heat Island Intensity across six stations distributed along the urban-to-suburban gradient. Their findings are structurally consistent with the thermal inversion documented in Chapter 7. Stations embedded in dense urban fabric register the highest nighttime UHI Intensity, rising to 2.60 °C during heatwave episodes, the thermal mass of the Pietra Leccese core retaining and releasing daytime heat through the night. Stations surrounded by green areas or located in suburban settings register the lowest values, confirming that the ecological buffer function the RUTZ Index maps spatially is also detectable as a nighttime temperature signal at the station scale.

The cross-comparison between the ARPA station record and the Landsat LST raster reveals a systematic scale divergence. The station-derived UHI Intensity peaks during daytime heatwave periods at the fringe stations while the urban core registers its maximum contribution at night, a temporal inversion that mirrors the spatial inversion Chapter 7 identified. Donateo et al. (2023), tracking nine years of station data across Lecce from 2013 to 2021, confirm a statistically significant deterioration of thermal comfort across the monitoring period, tracking the simultaneous progression of fringe sprawl and Xylella-driven canopy collapse. The multi-year station record is the temporal companion to the

spatial cross-section that the RUTZ fishnet provides. Detailed station-level UHll profiles are reported in Pappaccogli et al. (2024, Figure 5) and are not reproduced here. Together, they establish that the thermal argument of this thesis is not an artifact of a single heatwave date or a single Landsat scene: it is a structural territorial condition.

8.2 The HRI: Construction, Inputs, and Spatial Results

8.2.1 Instrument Design

The Heat Risk Index is a composite spatial instrument adapted from the Esri GIS for Climate Action protocol, with Mediterranean-specific data substitutions at each input layer. Its purpose is operational rather than diagnostic: it identifies the census sections within the nine-municipality study area where extreme summer thermal exposure, deficient cooling canopy, and concentrated vulnerable population converge, and where targeted adaptation interventions, tree planting, cool surfaces, and shaded public space would yield the greatest reduction in human heat risk. The HRI operates at the administrative grain of the ISTAT census tract levels, distinct from the morphological grain of the RUTZ fishnet. Its output is not a refinement of the RUTZ classification but a complementary instrument that translates morphological risk into demographic risk: the two together define the highest-priority intervention zones in Chapter 10.

Three spatial inputs constitute the composite. The first is Land Surface Temperature, derived from the peak-summer 2025 Landsat 8/9 scene through the same Phase 4 thermal pipeline that supplies the RUTZ Thermal Time-Series fishnet, delivering emissivity-corrected surface temperature in degrees Celsius at 30-meter resolution. The second is canopy deficit: the fraction of each census section lacking tree cover, derived by inverting the mean Tree Cover Density extracted from the Copernicus HRL TCD 2023 raster at 10-meter resolution. A section with zero mean TCD returns a canopy-deficit value of 100%, the modal condition across the study area. The third is population density, calculated from the 2024 ISTAT census section total population divided by section area in square kilometers.

Each input is Min-Max normalized to a common 1–5 scale, eliminating unit differences between degrees Celsius, persons per square kilometer, and percentage, using the Standardize Field tool in ArcGIS Pro. The composite Heat Risk Index is the arithmetic sum of the three normalized scores. The theoretical range is therefore 3 (minimum exposure on all three axes simultaneously) to 15 (maximum on all three). The empirical range observed across the 1,784 census sections of the study area is 3.48 to 13.90.

8.2.2 Dataset Construction and Methodological Decisions

The ISTAT census section layer was extracted from the ArcGIS Living Atlas 2024 census dataset using a center-in selection against the nine-municipality study boundary. The initial extraction returned 1,844 census sections. Sixty sub-pixel sliver polygons, sections whose geometric area fell below the 900 m² area of a single 30-meter Landsat thermal pixel, were

excluded before analysis because Zonal Statistics' pixel-center inclusion rule produced null or unreliable LST means for them. The excluded sections carried fewer than 100 persons collectively. The cleaned analytical dataset, hereafter the HRI dataset, comprises 1,784 census sections covering 1,763 sections in the nine core study municipalities and 21 sections in proximate municipalities at the boundary of the extraction.

Zonal Statistics as Table was applied to the LST raster of summer 2025 and the Tree Cover Density raster separately, joined to the census section layer on the unique section identifier, and computed into the canopy-deficit percentage and population-density fields as described above. The Min-Max normalization step used 1 and 5 as the target minimum and maximum, mapping the lowest observed value on each input to 1 and the highest to 5, regardless of the theoretical maximum of the input variable. This is a section-relative normalization: a section is ranked in relation to the 1,784 sections in the study area, not in relation to any absolute standard of thermal danger or population concentration. The composite therefore measures relative vulnerability within this territory, not absolute heat risk in a global sense.

8.2.3 Spatial Results: Municipality-Level Profile

The nine-municipality HRI profile reveals a consistent spatial pattern. Working Hypothesis 3, that satellite municipalities would return higher per-section HRI mean values than the city of Lecce, despite their smaller total populations is confirmed. The six satellite towns that form the operational peri-urban band (Surbo, Lequile, Lizzanello, Cavallino, San Cesario di Lecce, San Pietro in Lama) return an average composite HRI of 9.66 against Lecce city's 9.33. The gap is modest in absolute terms but consistent across all six satellite municipalities: not one records a mean HRI below the Lecce city mean.

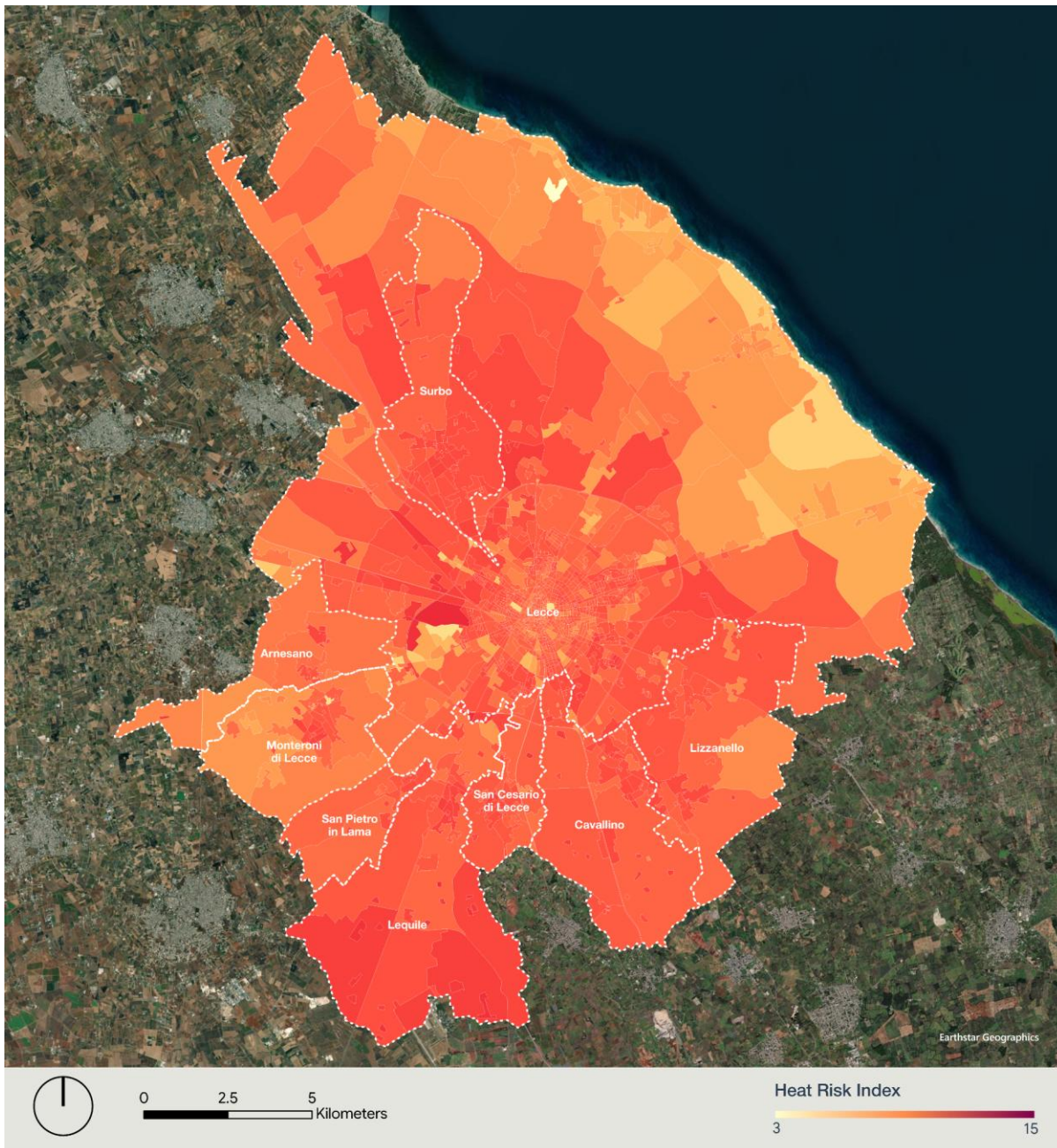
Table 8.1 Heat Risk Index by municipality, nine-municipality study area. Sorted by mean composite HRI (descending).

Municipality	Sections	Population	Mean HRI	Max HRI	Mean LST	TCD Lacking	Mean Pop.Dens.
Lequile	59	8,567	9.98	10.70	70.38°	97.1%	825
Surbo	56	14,531	9.85	10.28	69.74°	98.3%	2,072
San Pietro in Lama	13	3,371	9.73	10.26	69.76°	96.7%	1,504
Lizzanello	38	11,688	9.70	10.53	69.72°	96.5%	1,203
Cavallino	72	12,891	9.69	10.31	69.68°	96.7%	959
San Cesario di Lecce	41	7,883	9.69	10.44	69.82°	95.7%	1,988
Arnesano	26	3,922	9.40	10.36	69.54°	93.3%	773
Lecce	1,414	94,416	9.33	11.36	68.58°	96.7%	4,618

Municipality	Sections	Population	Mean HRI	Max HRI	Mean LST	TCD Lacking	Mean Pop.Dens.
Monteroni di Lecce	44	13,195	9.20	10.18	69.38°	91.1%	2,359

Source: LST Landsat 8 Collection-2 Level-2, Summer 2025 peak scene. TCD: Copernicus HRL Tree Cover Density 2023. Population: ISTAT 2024 census sections via ArcGIS Living Atlas.

Figure 8.1 Census Section Composite Heat Risk Index across Nine Municipalities



Note. Composite Heat Risk Index across 1,784 ISTAT census sections, nine-municipality study area, Lecce Province. Theoretical range: 3–15; empirical range: 3.48–13.90. Source: author's analysis; ISTAT 2024 census sections via ArcGIS Living Atlas; Landsat 8 Collection-2 Level-2 Summer 2025; Copernicus HRL TCD 2023.

The municipality-level pattern reflects the structural argument of Chapter 7. Lequile returns the highest mean HRI (9.98) despite housing only 8,567 residents. Its high rank is driven not

by population density, which is the lowest of all nine municipalities (825 persons/km²), but by the combination of the highest mean LST in the study area (70.38 °C) and the most extreme canopy deficit (97.1% lacking). The thermal exposure in Lequile's census sections is not concentrated in any single section but distributed across the full territory, a broad landscape-scale thermal loading rather than a localized hot-spot. This pattern is characteristic of the Stone ecology operating in summer: the open karst matrix bakes uniformly rather than burning in isolated peaks.

Surbo, by contrast, combines moderate LST with the most complete canopy absence in the study area (98.3 % TCD Lacking) and a moderate but consistent population density. Its mean HRI of 9.85 reflects a territory where the engineering of urban sprawl, sealed surfaces, minimal green infrastructure, and no planning-mandated canopy requirement has produced a systematic canopy void across an inhabited fringe. The difference between Lequile and Surbo in mechanism is the difference between geological exposure and planning failure: one is baked by karst, the other sealed by the logic of piecemeal villa development.

Lecce city itself presents the most analytically complex profile. Its mean HRI (9.33) is the lowest in the study area, confirming the cool-island effect of the dense historic core documented in Chapter 7. But its maximum HRI (11.36) is the highest in the study area — driven by specific high-density census sections in the city's inner ring where the accumulation of population in compact, older residential fabric intersects with elevated local LST and minimal canopy. These sections are not in the Pietra Leccese historic centre; they are in the mid-twentieth-century expansion zones where the limestone building tradition gave way to rendered concrete and where street trees are rare. The spread between Lecce's mean and maximum is the widest of any municipality (9.33 to 11.36), confirming a spatial heterogeneity internal to the city that the mean conceals: Lecce is simultaneously the most thermally comfortable municipality on average and the location of the most vulnerable populated sections in the study area.

8.2.4 Distributional Structure: What the Risk Bands Show

The HRI composite score across the 1,763 sections of the nine core municipalities distributes along a right-skewed profile anchored in the moderate-to-elevated range. The dominant risk band, elevated (HRI 9.5–10.5), absorbs 1,019 sections and 122,039 residents, approximately 72% of the study area's population. No section reaches the theoretical maximum of 15 in the study; the empirical ceiling of 13.9, a single Lecce city section, reflects the structural impossibility of extreme thermal exposure and maximum population concentration coinciding in the same 30-meter pixel mosaic in a city where the densest residential fabric is also the most shaded.

The planning significance of this distributional structure is that the dominant risk is not a crisis of outliers but a crisis of the middle: the 122,039 persons in the elevated sections are not the hottest or the most densely populated, but they are the ones for whom incremental

degradation of the thermal buffer, the conversion of one more green space, the sealing of one more agricultural parcel, the removal of one more street tree, actually produces the most tractable planning consequence. A canopy-planting program that achieves 10% canopy cover in an elevated section (reducing Tree Cover Density Lacking from 97% to 87%) would shift its normalized minimum and maximum lacking percentage score by approximately 0.4 to 0.5 points, enough, in many sections, to move from elevated to moderate risk without requiring any change in built fabric or population redistribution. This is the HRI's most direct planning implication, and it connects directly to the Point-Line-Surface intervention logic of Chapter 10.

8.3 Population Trends Across the Nine Municipalities

The nine municipalities recorded a combined population of 170,385 in 2019, rising to 170,515 in 2024, a net increase of only 130 persons over five years, well below the rate of natural change and consistent with the structural demographic stagnation that characterizes southern Italian metropolitan peripheries. Behind this near-stability is a profound internal recomposition. Five of the nine municipalities lost population: Monteroni di Lecce fell by 4.14%, Arnesano by 3.39%, San Pietro in Lama by 2.88%, San Cesario di Lecce by 2.49%, and Surbo by 1.04%. The four that gained, Cavallino (+2.65%), Lequile (+0.99%), Lizzanello (+0.94%), and Lecce city (+0.82%), are either the administrative and commercial center or the municipalities with the most active residential construction front, where land prices remain below those of the historic core and new villa development continues to convert former agricultural parcels into dispersed housing stock. The pattern is characteristic of what Indovina (1990) identified as the *città diffusa* dynamic: a regional population that is not declining in aggregate but redistributing itself along the paths of land-cost differentials, concentrating new residents in precisely the thermally most exposed territories while the older, more ecologically intact settlements decline.

The total population figure, however, conceals the change that matters most for the thermal vulnerability argument: the elderly population across the nine municipalities grew by 2,795 persons over the same five years, from 38,449 to 41,244, while the total population remained essentially flat. The elderly share rose from 22.57% to 24.19%, a gain of 1.62 percentage points in five years. In a stable-population system, this rate of aging means that roughly one in seven of the working-age residents who left the territory was replaced not by a younger arrival but by the natural progression of an existing resident into the 65+ class. The territory is not growing old because young people are being born; it is growing old because elderly people are living longer while the replacement generation migrates away. This is the demographic argument for urgency that the thermal analysis of Chapter 7 cannot supply on its own: the climate buffer is failing at precisely the moment when the population depending on it is the oldest it has ever been.

8.4 Age Structure, Dependency Ratios & Heat-Susceptible Cohorts

The clinical and epidemiological evidence on heatwave mortality is unambiguous about who is most at risk. Persons aged 65 and over face substantially elevated mortality risk during extreme heat events, and the risk intensifies with advancing age: a 2026 meta-analysis of older adult exposure across multiple health systems confirms that adults aged 75–84 and 85 and over face the highest heat-related health outcomes, with Mediterranean and subtropical zones registering the greatest impacts globally. Within the elderly cohort, gender compounds the risk further. A systematic review of European heat-wave mortality data found that elderly women are at higher risk than elderly men (Van Steen et al., 2019), and experimental physiological research at Penn State has now established that this disparity reflects genuine physiological difference rather than merely the demographic imbalance created by women's greater longevity: older women lose thermoregulatory capacity at lower temperature-humidity combinations than older men of equivalent age, and women between 40 and 64 are as physiologically vulnerable to heat as men aged 65 and over (Leach & Kenney, 2024). An Italian cohort study in Rome confirmed the clinical specificity of this pattern: in the 75+ age group, women and unmarried subjects were specifically identified as more susceptible to heat-wave mortality after controlling for pre-existing conditions (Baccini et al., 2009).

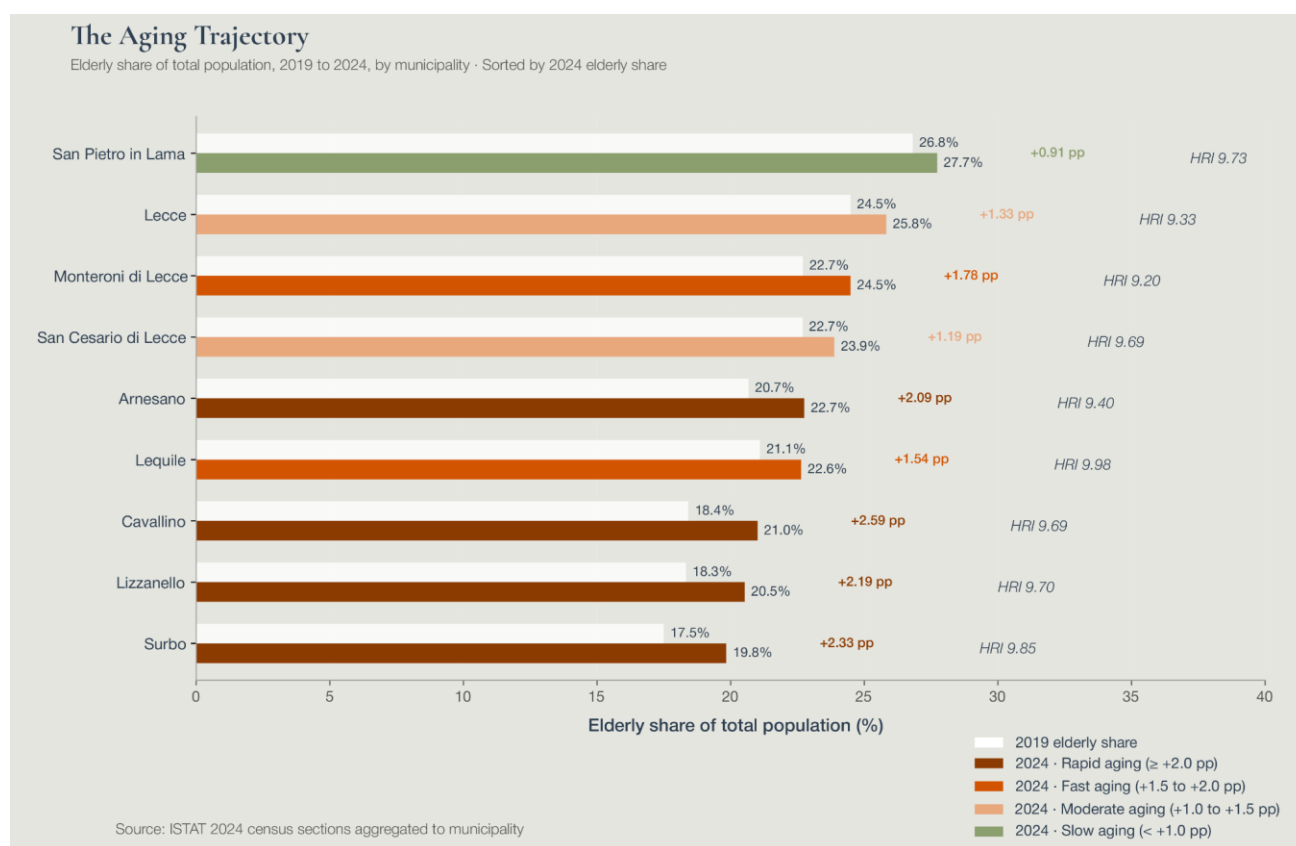
The nine-municipality study area presents a demographic structure that aligns precisely with this risk profile. Of the 41,244 persons aged 65 and over in 2024, 23,580, 57.16% are women. Across all nine municipalities, female elderly consistently outnumber male elderly: the share ranges from 54.83% in Lizzanello to 57.96% in Lecce, with no municipality in the study area below 54%. The physiological evidence implies that this majority is also the majority of the highest-risk residents in the territory, a claim that the demographic data confirms structurally rather than requires any individual health record to support.

The municipality-level aging structure reveals further spatial differentiation. Lecce city records the highest aging index in the study area (1.84), meaning there are 1.84 persons aged 65 or over for every child under 18, driven by the city's role as the territory's largest residential concentration and the progressive aging of its mid-twentieth-century expansion neighborhoods. San Pietro in Lama follows closely (1.81) with the highest elderly share of any municipality (27.72%) despite its small population. Monteroni di Lecce (1.73) and San Cesario di Lecce (1.53) complete the upper tier. Across all nine municipalities, every aging index exceeds 1.0, meaning the elderly outnumber children everywhere in the study area and the territory-wide average sits at approximately 1.5, a structural inversion that has no precedent in the region's demographic history and that quantifies what the thermal mapping of section 8.2 describes as a planning emergency.

The fastest-aging municipalities are not the oldest ones; they are the satellite towns. Cavallino gained 2.59 percentage points of elderly share between 2019 and 2024, the most rapid demographic aging of any municipality, followed by Surbo (+2.33pp) and Lizzanello

(+2.19pp). These are the same municipalities that score highest on the HRI's thermal-and-canopy-deficit composite. The demographic and thermal risk curves are not diverging across the territory; they are converging in the same satellite towns. Cavallino: aging fastest, HRI 9.69. Surbo: third-fastest aging, HRI 9.85. Lequile: highest mean HRI in the study area, with its own elderly share rising 1.54 percentage points across the same period. The convergence is not coincidental; it is the spatial logic of affordable peri-urban housing attracting older residents to thermally exposed territories precisely as those territories' ecological buffers are failing. Figure 8.2 renders the 2019–2024 aging trajectory municipality by municipality, establishing both the current level of elderly dependency and the rate at which it is accelerating.

Figure 8.2 Elderly Share Comparison 2019 vs 2024, All Nine Municipalities



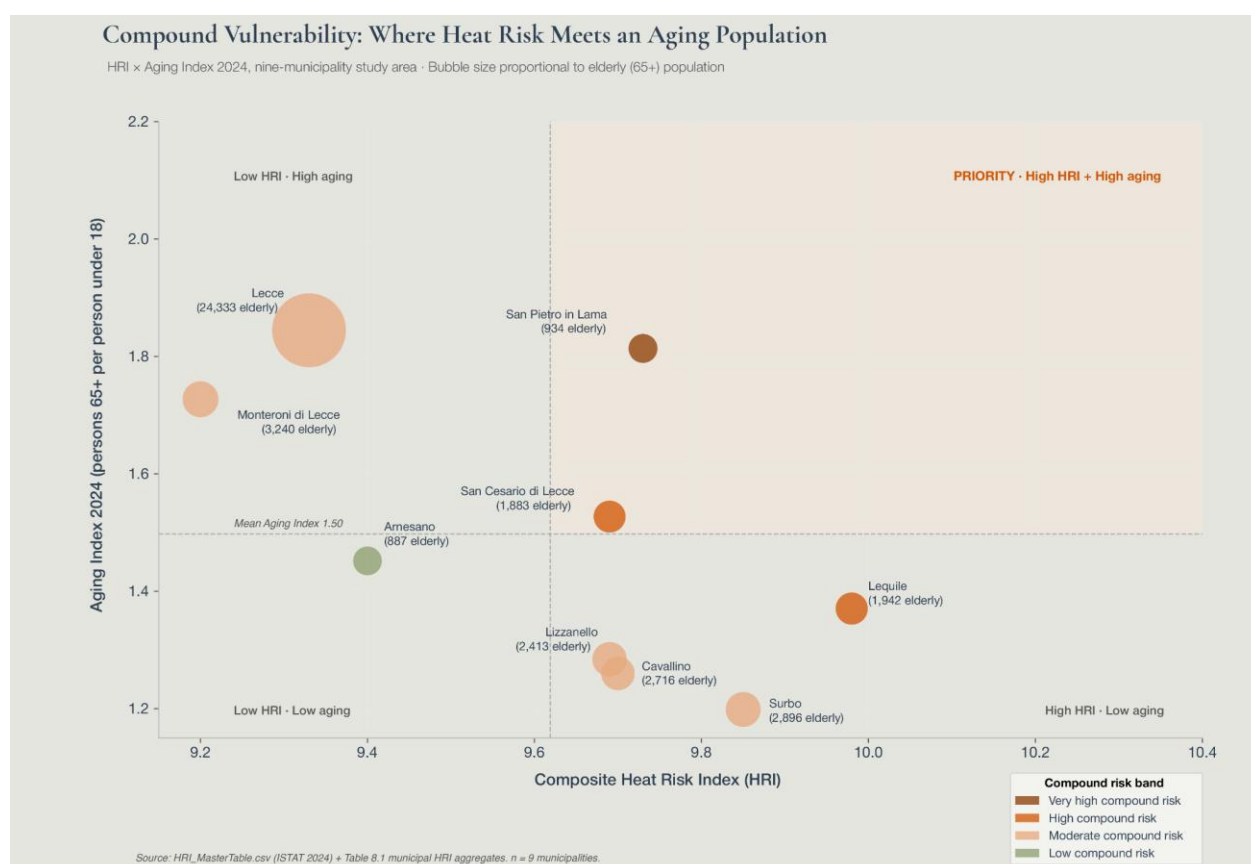
Note. Elderly population share (%) in 2019 (unfilled bars) and 2024 (filled bars) across all nine municipalities, sorted by 2024 elderly share (descending). Floating labels show the percentage-point change. Source: ISTAT 2024 and 2019

The dependency ratio, the ratio of the economically inactive population (children and elderly together) to the working-age population, reaches 0.755 in San Pietro in Lama, the highest in the study area, followed by Lecce (0.662) and San Cesario di Lecce (0.653). Five of the nine municipalities exceed a dependency ratio of 0.60. In planning terms, a high dependency ratio signals not only a demographic burden on public services but also a population that is less mobile, less able to self-evacuate during heatwave events, and more likely to be found at home without mechanical cooling during the hottest days of the Mediterranean summer.

8.5 Overlaying Vulnerability with Morphology: Where Bodies Meet Stone

The HRI and the RUTZ classification emerge from different analytical traditions; the former is a demographic and public-health instrument, the latter a morphological and ecological one, but their spatial overlap produces the thesis's most consequential planning argument. A census section that scores Elevated on the HRI and simultaneously sits within the Active Margin or Critical Fringe cells of the RUTZ peri-urban classification is a section where the morphological failure of the climate buffer intersects with the demographic concentration of a vulnerable population. It is where Stone ecology, the open, moisture-exhausted, baking karst matrix meets the bodies of elderly residents in affordable peripheral housing. That convergence is not incidental; it is the territorial logic of the Italian peri-urban condition.

Figure 8.3 HRI and Aging Index Compound Vulnerability Matrix



Note. Compound vulnerability matrix: nine municipalities plotted by mean HRI composite score (X axis) and Aging Index 2024 (Y axis). Bubble size is proportional to the total 2024 elderly population (65+). The upper-right quadrant (high HRI + high aging) defines the highest-priority intervention territories. Source: ISTAT 2024

The overlay of HRI census sections against RUTZ peri-urban classes reveals three spatial typologies of compounded risk. The first is the thermally exposed fringe with low population: sections in Lequile and the agricultural fringe of Surbo that score in the Elevated or High HRI band but carry few permanent residents. The thermal exposure is severe; the immediate demographic risk is contained. These sections are priority candidates for canopy-restoration interventions (the Surface strategy of Chapter 10) that preemptively restore cooling capacity before residential development intensifies.

The second typology is the populated satellite town section: sections in the inner rings of Cavallino, Lizzanello, and San Cesario di Lecce where moderate thermal exposure intersects with population densities of 800–2,000 persons/km² in low-rise residential fabric with minimal street-tree provision. These sections score in the Elevated band and carry the majority of the study area's heat-exposed permanent residents and, as section 8.4 establishes, these are also the municipalities ageing fastest. Interventions here are urban: street-tree planting along residential roads, shaded public space in courtyard formations (the Point strategy of Chapter 10), and linear canopy along the muretti a secco network connections between residential parcels and surviving agricultural green (the Line strategy).

The third typology is the dense urban vulnerability hotspot: specific sections in the Lecce inner ring, mid-twentieth-century residential blocks in the expansion neighborhoods between the historic center and the Tangenziale, where compact form, aging building stock, minimal private outdoor space, and limited public canopy converge to produce the study area's maximum HRI values. These sections are thermally moderated at the neighborhood scale by the limestone core nearby but poorly protected at the parcel scale, and their elderly residents, disproportionately women, per section 8.4, in dwellings without mechanical cooling, represent the acute heatwave mortality risk that the HRI was designed to surface. The intersection of maximum HRI (11.36 in the most exposed section) with Lecce's territory-wide aging index of 1.84, the highest of any municipality, defines the thesis's most urgent planning claim: the climate buffer's failure is not only a morphological emergency at the fringe, but a demographic emergency in the city.

Chapter 9

CHAPTER 9 — The RUTZ Index: Construction, Calibration & Cartography

Chapters 6 and 7 have built the RUTZ Index's two component readings: the peri-urban gradient and the ecological identity, and tested the second against the thermal record without prior knowledge of it. This chapter formalizes the Index as a single analytical instrument: it states its conceptual architecture against the Five Research Pillars of Chapter 3, restates its variable selection and normalization logic as a closed specification, reports the thermal validation test the design promised in section 4.5, examines the robustness of the weighting scheme under perturbation, situates the Index cartographically, and confronts it with the Local Climate Zone framework whose documented failures in the Mediterranean fringe (section 2.3.4) motivated the Index's construction in the first place.

9.1 Conceptual Architecture of the Index: From Five Pillars to One Composite

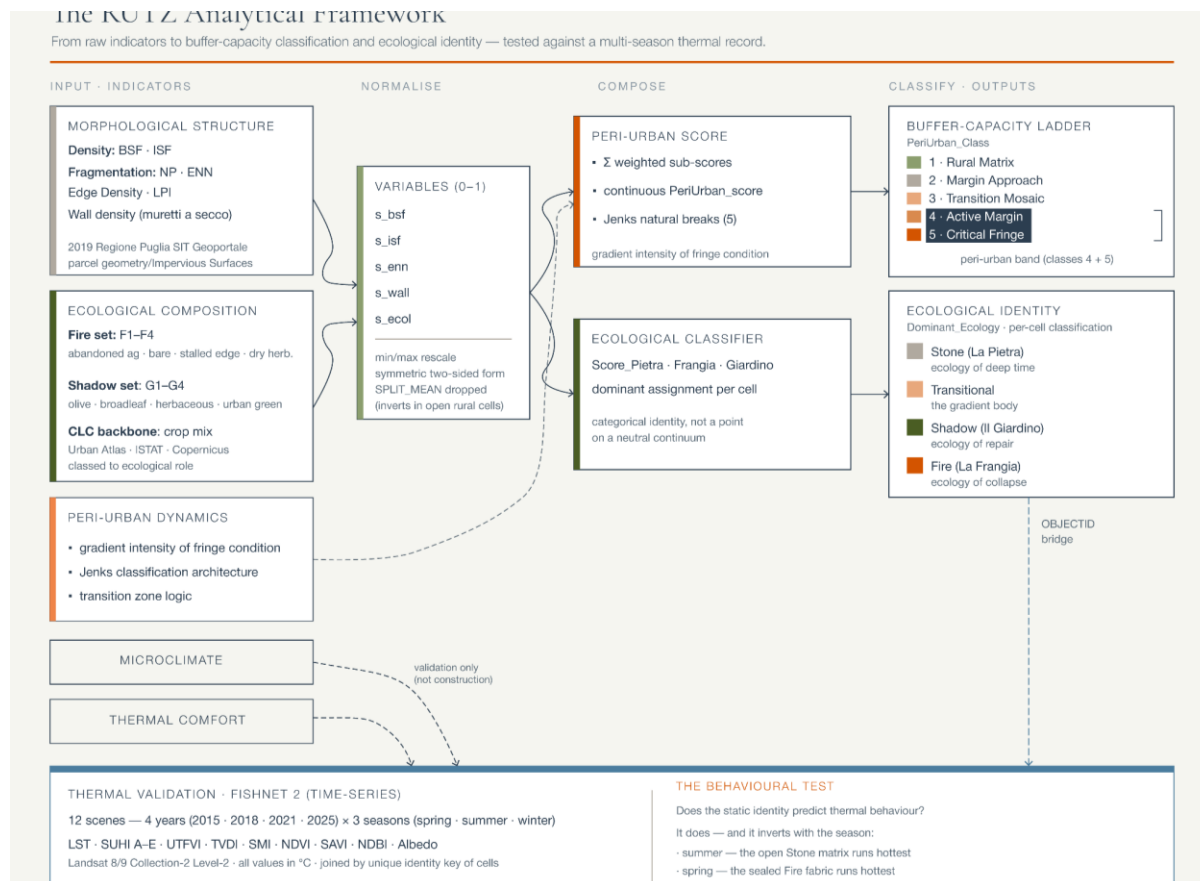
Chapter 3 assembled the theoretical framework into Five Research Pillars — Morphology, Ecological Role, Microclimate, Peri-Urban Dynamics, and Thermal Comfort — through which the Lecce fringe is read as a single, interacting territorial system rather than five separate disciplinary objects. The RUTZ Index is the instrument that translates these five pillars into one operative composite, and its architecture is best understood as a deliberate mapping between pillar and pipeline output.

The Morphology pillar is carried by the Building Surface Fraction and Impervious Surface Fraction sub-scores (s_{bsf} , s_{isf}) and by the fragmentation stack — Number of Patches, Largest Patch Index, Edge Density, and the Euclidean Nearest-Neighbor distance that survives into the composite as s_{enn} . The Ecological Role pillar is carried by the ecology composition sub-score (s_{ecol}), the normalized balance of Fire-type and Shadow-type coverage within each cell that the Phase 1–3 cross-validation pipeline delivers. The Peri-Urban Dynamics pillar, the gradient logic itself is not a sixth sub-score but the architecture that holds the other four together: it is the Jenks-classified composite that converts five independent measurements into a single ordinal reading of transition intensity. The Microclimate and Thermal Comfort pillars are deliberately absent from the composite's construction. This absence is not an omission; it is the Index's central methodological commitment, restated here because its consequence is what this chapter exists to test: the thermal record is held out of the Index's construction so that it can serve, independently, as the validation the Index's classification deserves or does not deserve.

This architecture produces the two-track structure that Chapter 4 established and that Chapters 6 and 7 have each populated with one track: the peri-urban gradient ladder (Rural Matrix through Critical Fringe, section 6.6) reading how transitional each cell is, and the dominant ecology classification (Stone, Shadow, Fire, Transitional, sections 7.1–7.2) reading

which metabolic logic it follows. The RUTZ Index, properly understood, is not either track alone. It is the paired reading: a cell's position on both axes simultaneously, reported together as the Index's complete output for that hectare. Figure 9.1 renders this architecture as a single diagram, tracing the path from the Five Pillars through the indicator families, the five sub-scores, and the two composite tracks, to the validated output this chapter reports.

Figure 9.1 The RUTZ Index Architecture: From Five Research Pillars to Two Composite Tracks



Note. The RUTZ Index's conceptual architecture extends Figure 4.3 with the Five Research Pillars (Morphology, Ecological Role, Microclimate, Peri-Urban Dynamics, Thermal Comfort) layered above the indicator → sub-score → composite pipeline. Microclimate and Thermal Comfort pillars are shown as held outside the construction pathway, feeding in only as the independent validation layer reported in §9.3. *Source:* author's schematic visualization, extending Figure 4.3.

9.2 Variable Selection and Normalization

This section restates, as a closed specification, the variable architecture that Chapters 4 through 6 progressively constructed and justified. Five sub-scores enter the peri-urban composite: s_bsf and s_isf (Building and Impervious Surface Fraction, the morphological density pair); s_enn (Euclidean Nearest-Neighbor distance, the surviving fragmentation indicator after the SPLIT_MEAN exclusion documented in section 5.7); s_wall (dry-stone wall density, the thesis-specific vernacular infrastructure indicator); and s_ecol (the ecology composition balance). Each is rescaled to a common interval using the symmetric two-sided

normalization form established in section 4.4 and section 6.6, replacing the earlier asymmetric Inverted U transform that inflated the scores of open rural cells by misreading their emptiness as a peri-urban signal.

Table 9.1 reports the correlation structure among the five sub-scores, computed across all 8,625 cells of the study grid. The matrix is the formal evidentiary basis for treating the five sub-scores as substantially independent measurements rather than restatements of the same underlying signal, a precondition for any composite index that claims to integrate distinct dimensions of territorial condition rather than amplify a single one.

Table 9.1 Sub-Score Correlation Matrix (Pearson r , $n = 8,625$ cells)

	BSF	ISF	ENN	Wall	Ecology
BSF	1.00	0.25	-0.05	-0.20	-0.26
ISF	0.25	1.00	0.07	-0.04	-0.15
ENN	-0.05	0.07	1.00	-0.01	0.04
Wall	-0.20	-0.04	-0.01	1.00	0.04
Ecol	-0.26	-0.15	0.04	0.04	1.00

Source: author's analysis; FISHNET Master Profile fields, 5 scoring criteria. The strongest inter-correlation is between BSF and ISF ($r = 0.25$), an expected and modest relationship between the two built-density measures; wall density correlates negatively with BSF ($r = -0.20$) and with ecology composition ($r = 0.04$), confirming that the wall network is concentrated in open, non-built, agriculturally coded cells rather than duplicating the built-density signal. No pair exceeds $r = 0.30$ in absolute value: the five sub-scores measure substantially distinct territorial dimensions.

9.3 Weighting and Calibration

The composite Peri-Urban Score weights the five sub-scores equally. This is a deliberate methodological choice rather than a default: with no a priori theoretical basis for asserting that built density matters more than wall density, or that ecological composition outweighs patch isolation, in determining a cell's peri-urban condition, an unweighted composite is the position that imposes the least unjustified structure on the data. The validity of this choice is tested empirically in section 9.6 below.

9.3.1 The Thermal Validation Test

Section 4.5 committed the thesis to a specific validation discipline: because the thermal record is held entirely out of the Index's construction, any correlation between the Index's classification and the independently measured thermal behaviour of the territory constitutes genuine validation rather than a circular restatement of the same evidence. This section reports the test.

The continuous Peri-Urban Score correlates with mean summer Land Surface Temperature across all four years of the record, and the sign of the correlation inverts between spring and summer in exact agreement with the seasonal inversion documented in Chapter 7. In

every summer scene, the correlation is negative — a higher peri-urban score (a cell further along the transition gradient, toward the Active Margin and Critical Fringe) predicts a lower summer LST: Summer 2015 $r = -0.274$, Summer 2018 $r = -0.138$, Summer 2021 $r = -0.255$, Summer 2025 $r = -0.22$ (all $p < 0.001$, $n = 8,625$). In every spring scene, the correlation reverses sign: Spring 2015 $r = +0.11$, Spring 2018 $r = +0.074$, Spring 2021 $r = +0.249$, Spring 2025 $r = +0.246$ (all $p < 0.001$). The peri-urban gradient, built entirely from morphology, fragmentation, wall density, and ecological composition, with no thermal input whatsoever, predicts the direction of the seasonal thermal behavior that Chapter 7 established as the thesis's central empirical finding, and it predicts it with the correct sign in eight consecutive scenes spanning four years.

The dominant ecology classification is submitted to the same test with an independent statistical method. A one-way ANOVA of summer 2025 LST across the four ecology classes (Stone, Shadow, Fire, Transitional) returns $F = 477.6$ ($p < 0.001$), with the ecology classification explaining $\eta^2 = 14.3\%$ of the total variance in summer surface temperature across 8,625 cells, a substantial effect size for a classification built without any thermal input. The classification's predictive power is strongest in spring ($\eta^2 = 18.8\%$) and somewhat attenuated but still highly significant in summer ($\eta^2 = 14.3\%$), consistent with the dry-summer decoupling argument of section 7.3: the ecologies remain thermally distinguishable in both seasons, but the margin of distinction narrows as the Mediterranean drought erodes the spring moisture advantage that most cleanly separates them.

Together, these two tests answer the question sections 4.5 and 7.9 posed and deferred: a classification built blind to temperature does reproduce a coherent, season-dependent thermal structure, in both its continuous gradient form and its categorical ecology form, with statistical significance that leaves no plausible alternative reading. This is the strongest validation the RUTZ Index's design can offer, and it is offered here as the formal closure of the methodological commitment made at the chapter's outset in Part II of the thesis.

9.3.2 Calibration Note: Weight Equality as the Defensible Default

The decision to weight the five sub-scores equally was tested, not merely asserted, through the sensitivity analysis reported fully in section 9.6. The summary finding, anticipated here because it bears directly on the calibration claim: the equal-weight composite correlates at $r = 0.985$ with a naively averaged five-variable mean, confirming that the symmetric normalization and the equal-weight summation are functioning as intended and are not silently privileging any single sub-score through scale artefacts. The calibration is sound at the level the thesis's resolution and timeline can support; a future doctoral-scale extension could explore expert-elicited or Analytic Hierarchy Process (AHP) weighting schemes against the same thermal validation benchmark established here, a research continuation path named explicitly in sections 10.5 and 11.3.

9.4 Cartographic Expression: The Buffer-Capacity Gradient

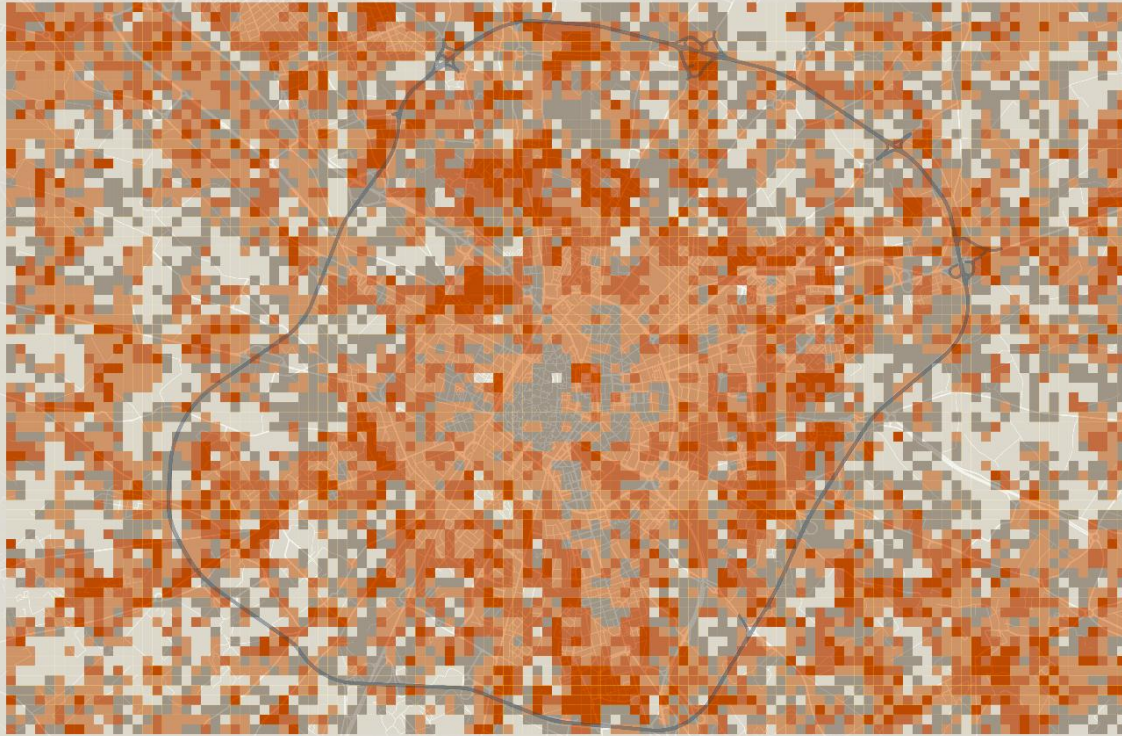
The RUTZ Index's cartographic output is the five-class peri-urban gradient choropleth first presented as Figure 6.7 in section 6.6, here reproduced and read as the Index's validated final cartography rather than its provisional construction. The map's classification, Rural Matrix, Margin Approach, Transition Mosaic, Active Margin, Critical Fringe is, after the validation reported in section 9.3, no longer simply a Jenks-classified composite score; it is a classification demonstrated to track an independently measured thermal behavior with statistical significance across four years and twelve scenes.

Figure 9.2 presents the buffer-capacity gradient alongside its thermal validation directly: a paired cartographic and statistical figure in which the five-class choropleth (top panel) sits beside the summer LST choropleth at the same extent and scale (bottom panel), allowing the reader to confirm visually what section 9.3 establishes statistically, the reverse-UHI gradient running from Rural Matrix to Critical Fringe is legible as a spatial coincidence between the two independently constructed maps, not merely a correlation coefficient in a table.

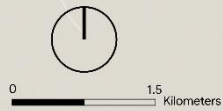
Figure 9.2 Buffer-Capacity Gradient with Thermal Validation Pairing

Peri-Urban Cell Identification

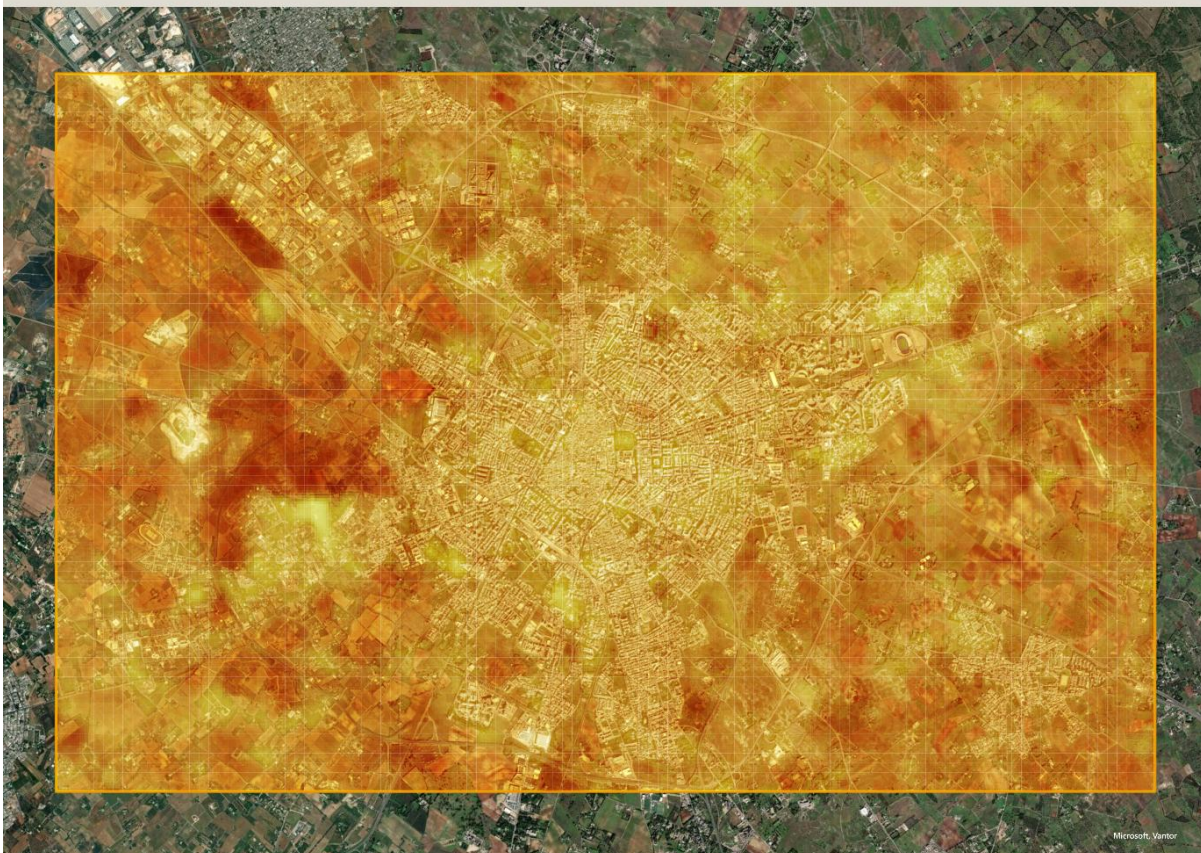
RUTZ Index - Morphological delineation of the Lecce peri-urban interface



Sources: Esri, TomTom, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community



Top: morphological gradient (RUTZ Peri-Urban Score, five Jenks classes), constructed from built form, fragmentation, wall density, and ecology composition, no thermal input. **Bottom:** mean summer Land Surface Temperature, Summer 2025. The spatial ordering of both maps follows the same direction.



9.5 Comparison with Standard LCZ Classification

Working Hypothesis 2 (section 1.4) predicted that the Local Climate Zone framework would systematically misclassify the cells of the transition zone, with the misclassification concentrated precisely in the cells that matter most thermally. Chapter 2 (section 2.3.4) assembled the published evidence for this prediction at the literature level: Demuzere et al. (2019) document a 32% classification accuracy for the sparsely-built LCZ 9 category, the class that most closely describes the Lecce fringe's dominant morphology against a global mean building-class accuracy of 48% (Ren et al., 2019); Pappaccogli et al. (2025), working with the Lecce case directly, demonstrate that the WUDAPT-derived LCZ map systematically overestimates LCZ 6 and LCZ 8 (open and large low-rise) while underrepresenting more compact types, and that the resulting LST distributions diverge significantly between GIS-based and WUDAPT-based classification methodologies for the same territory.

This thesis does not perform an original pixel-by-pixel LCZ classification of the Lecce fringe against which to run a direct spatial confusion-matrix comparison: no LCZ raster for the nine-municipality study area exists in the project's data inventory, and producing one by training a WUDAPT-compliant classifier on local imagery, or executing the GIS-based reclassification method Pappaccogli et al. (2025) describe, falls outside the scope and timeline this thesis can accommodate before submission. The comparison offered here is therefore evidentiary and structural rather than a new spatial overlay: it reads the RUTZ Index's demonstrated performance (section 9.3) against the published LCZ accuracy figures for directly comparable Mediterranean fringe contexts, including Lecce itself.

Three points of comparison follow from this evidentiary reading. First, where LCZ 9 achieves 32% classification accuracy in sparsely built peri-urban contexts (Demuzere et al., 2019), the RUTZ ecology classification achieves a statistically significant thermal separation ($\eta^2 = 14.3\text{--}18.8\%$, section 9.3.1) using a methodology built specifically for, and validated against, the Lecce territory rather than transferred from a global training set calibrated on non-Mediterranean cities. Second, where Pappaccogli et al. (2025) demonstrate that the LCZ framework's classification method materially changes the thermal conclusions drawn from the same territory, the RUTZ Index's two-track architecture, gradient and ecology, both validated against the same independent thermal record, offers a single, internally consistent classification whose thermal correlation is reported transparently rather than discovered as a post hoc discrepancy between competing classification methods. Third, and most directly responsive to Working Hypothesis 2's specific prediction, the RUTZ Index resolves at the 100-meter cell precisely the heterogeneous fringe mosaic, sealed driveway, dead olive grove, incomplete and villa clusters, dry-stone wall fragment, that LCZ's neighborhood-scale homogeneity assumption (section 2.3.4.2) cannot hold apart, because the RUTZ pipeline was constructed from the outset to integrate morphology, fragmentation, and ecology composition at exactly this resolution rather than to assign a single dominant typology per classification unit.

9.6 Sensitivity Analysis and Robustness Testing

A composite index calibrated on a single weighting scheme risks reporting an artefact of that scheme rather than a genuine territorial pattern. This section tests the RUTZ peri-urban classification's robustness against two perturbations of its construction: removal of the wall-density sub-score, and removal of the ecology-composition sub-score, the two sub-scores most distinctive to this thesis's specific methodological contribution and therefore the two whose influence on the final classification most deserves scrutiny.

Removing wall density and re-deriving a four-variable composite score (s_{bsf} , s_{isf} , s_{enn} , s_{ecol} only) produces a score that correlates with the original five-variable composite at $r = 0.904$, a strong but not perfect relationship confirming that wall density contributes genuine, non-redundant information to the original composite. Re-classifying this four-variable score into five quintile-based classes and comparing cell-by-cell against the original Jenks-classified five-class scheme yields an exact class agreement of 49.3%, moderate agreement, as expected given that quintile and Jenks classification use different breakpoint logics even on highly correlated underlying scores. The operationally decisive comparison is narrower and more reassuring: of the 2,469 cells originally classified as Active Margin or Critical Fringe, 91.3% remain in the equivalent operational band under the wall-excluded scheme. The cells the thesis identifies as the priority intervention domain in Chapter 10 are not an artefact of the wall-density sub-score's particular weighting; they are robust to its removal.

Removing the ecology-composition sub-score performs a more demanding test, because s_{ecol} is the sub-score most directly implicated in the section 6.6 discussion of the shared evidence base between the peri-urban gradient and the dominant ecology classification. A three-variable composite (s_{bsf} , s_{isf} , s_{enn} only) correlates with the original five-variable composite at $r = 0.866$, somewhat weaker than the wall-exclusion test but still a strong relationship. Operational-band retention under this more aggressive exclusion is 87.4%, lower than the wall-exclusion case, confirming that ecology composition does meaningfully shape which cells fall into the operational band, exactly as the architecture in sections 6.6 and 9.1 intends. This is the expected and desired result, not a vulnerability: s_{ecol} is supposed to matter, because it is the sub-score that carries the cross-validated Phase 1–3 evidence that the morphological metrics alone cannot supply. The sensitivity test confirms that the composite's two most thesis-specific contributions, the author-built wall dataset and the cross-validated ecology composition, both carry genuine, non-redundant analytical weight, rather than one silently dominating or duplicating the other.

Table 9.2 summarises the sensitivity analysis. The pattern across both perturbation tests is consistent: the operational band is moderately to substantially robust to single-variable removal, more robust to the removal of wall density than to the removal of ecology composition, and never collapses below 87% retention even under the more aggressive exclusion. The RUTZ Index's classification of the priority intervention domain is not

contingent on any single sub-score; it is the product of the composite's full five-variable architecture functioning as intended.

Table 9.2 Sensitivity Analysis: Sub-Score Removal and Operational Band Stability

Perturbation scheme	r vs. original score	Exact class agreement	Operational band (Cl. 4+5) retention
Full 5-variable composite (baseline)	—	—	2,469 (100%)
Excluding wall density (s_wall)	0.904	49.3%	91.3% retained
Excluding ecology composition (s_ecol)	0.866	43.1%	87.4% retained

Note. Operational band = cells classified Active Margin or Critical Fringe (Peri-Urban Class 4 or 5) under the original five-variable equal-weight Jenks scheme, $n = 2,469$. Retention = share of these original operational cells still classified in the equivalent top-two-quintile band under each perturbed scheme. *Source: author's analysis; FISHNET Master Profile dataset.*

This sensitivity analysis closes the chapter's calibration argument. The RUTZ Index, as constructed, validated, and stress-tested here, is the instrument Chapter 10 applies to the operational peri-urban band, and the chapter has now demonstrated, rather than merely asserted, that this band is a robust territorial finding rather than a methodological accident of any single weighting decision.

Chapter 10

CHAPTER 10 — Discussion: Strategic Proposals & Policy Integration

Chapter 9 calibrated the RUTZ Index as the operative instrument for reading the Lecce peri-urban fringe at the hectare scale. Chapter 10 turns the instrument toward the design question that has accompanied the analytical argument from the first page: where, and through what spatial gestures, can the climate buffer be restored before the territory in which it operates dissolves? The chapter proposes a design-led, incremental Point–Line–Surface (PLS) framework and applies it to the 2,469 cells of the operational peri-urban band, the Active Margin and the Critical Fringe as the strategic intervention domain that the RUTZ Index and the Heat Risk Index together identify. The prototypes serve as the visuals of how these incremental design strategies can address the thermal and ecological challenges identified in the study.

10.1 Reading the Lecce Buffer: What the RUTZ Index Reveals

The empirical chapters of Part III have established a buffer in three different registers, each at a different analytical scale. At the scale of the four ecologies (Chapter 7), the buffer mechanism is seasonal and discontinuous: Stone (the open karst-and-wall matrix) and Shadow (the surviving olive and herbaceous mosaic) provide measurable cooling in spring through their moisture-supported evapotranspiration, then collapse under the Csa summer drought as the karst water battery exhausts and the surface temperature ranking inverts. At the scale of the peri-urban gradient (Chapter 6), the buffer is structural: summer Land Surface Temperature falls monotonically from the Rural Matrix (46.85 °C, four-year mean) to the Critical Fringe (45.48 °C). This 1.37 °C decline constitutes the reverse urban heat island gradient at hectare resolution. And at the scale of the human population (Chapter 8), the buffer is demographic: the satellite municipalities that score highest on the composite Heat Risk Index — Lequile, Surbo, Lizzanello, Cavallino, San Cesario di Lecce — are precisely the municipalities ageing most rapidly between 2019 and 2024, concentrating the elderly cohort whose physiological vulnerability to heat (Leach & Kenney, 2024; Baccini et al., 2009) compounds the territorial thermal exposure documented by the satellite record.

Three findings from this analysis become the empirical foundation for the design strategy that follows. The first is that the Active Margin and the Critical Fringe, the two upper bands of the peri-urban classification, are not the hottest cells in the study area but the cells whose buffering mechanisms are still functional yet being eroded progressively. Summer NDMI in the Critical Fringe averages –0.043 against the Rural Matrix's –0.091; summer BSI averages 0.108 against the Rural Matrix's 0.150 (Appendix B.1.3, 4-year summer means). The operational band carries marginally more canopy moisture and marginally less bare-soil exposure than the deeper rural territory beyond it, a signature consistent with the surviving olive groves, the residual herbaceous understory, and the dry-stone wall infrastructure that the Phase 1–3 cross-validation pipeline identifies as concentrated precisely at the interface

between the urban edge and the agricultural matrix. The buffer mechanism is still present at the operational band. It is what intervention must protect.

The second finding is that the cells where this buffer is concentrated coincide with the cells where the resident population most exposed to heatwave mortality risk also concentrates. The high-HRI satellite municipalities are not abstract administrative territories; they are the spatial substrate on which the operational peri-urban band sits. The 2,469 cells of Classes 4 and 5 cover approximately 247 km² of the study area; that territory contains the residential blocks in the inner suburban fringes of Lecce city, where the convergence of elderly residents, low canopy cover, high exposure to solar radiation, and elevated summer surface temperature defines the planning vulnerability of the next decade. Intervening in the buffer mechanism is intervening in the demographic vulnerability that depends on it.

The third finding is mechanistic. Section 7.7 isolated moisture and surface exposure, not albedo, as the dominant drivers of the seasonal thermal ranking. Summer LST correlates with NDMI at $r = -0.67$ and with BSI at $r = +0.59$ across the grid, with albedo at $r = -0.06$. At the hectare scale of the fringe, the cooling work is done by the moisture cycle and the canopy that sustains it, not by surface reflectivity. This is consequential for design: the intervention strategy must address moisture, shade, and surface vegetation, and need not invest in albedo modification (cool pavements, light-color surfaces) at the territorial scale. The vernacular intelligence of Pietra Leccese already provides whatever albedo benefit the urban material can supply at the building scale. The territorial buffer is biological, hydrological, and structural, and the design strategy must be the same.

10.2 The Point–Line–Surface Framework: A Design Strategy for the Active Margin

The Point–Line–Surface (PLS) framework, developed, proposes a design-led, incremental strategy for the peri-urban fringe of Lecce, the zones of degradation and vulnerability, calibrated to act on the territory through three distinct spatial registers that correspond to three distinct conditions of thermal stress and ecological opportunity. Rather than a fixed masterplan that imposes a single design logic across a heterogeneous territory, the PLS framework operates as a toolkit: each Point, Line, and Surface intervention is sited where its specific spatial logic responds to a measurable territorial condition that the RUTZ Index has identified. The toolkit's design principle is that of 'minor acts of repair' (Casagrande, 2020), incremental and maintenance-based interventions that leverage the karst geomorphology and the vernacular material culture of the Salento rather than imported infrastructural solutions.

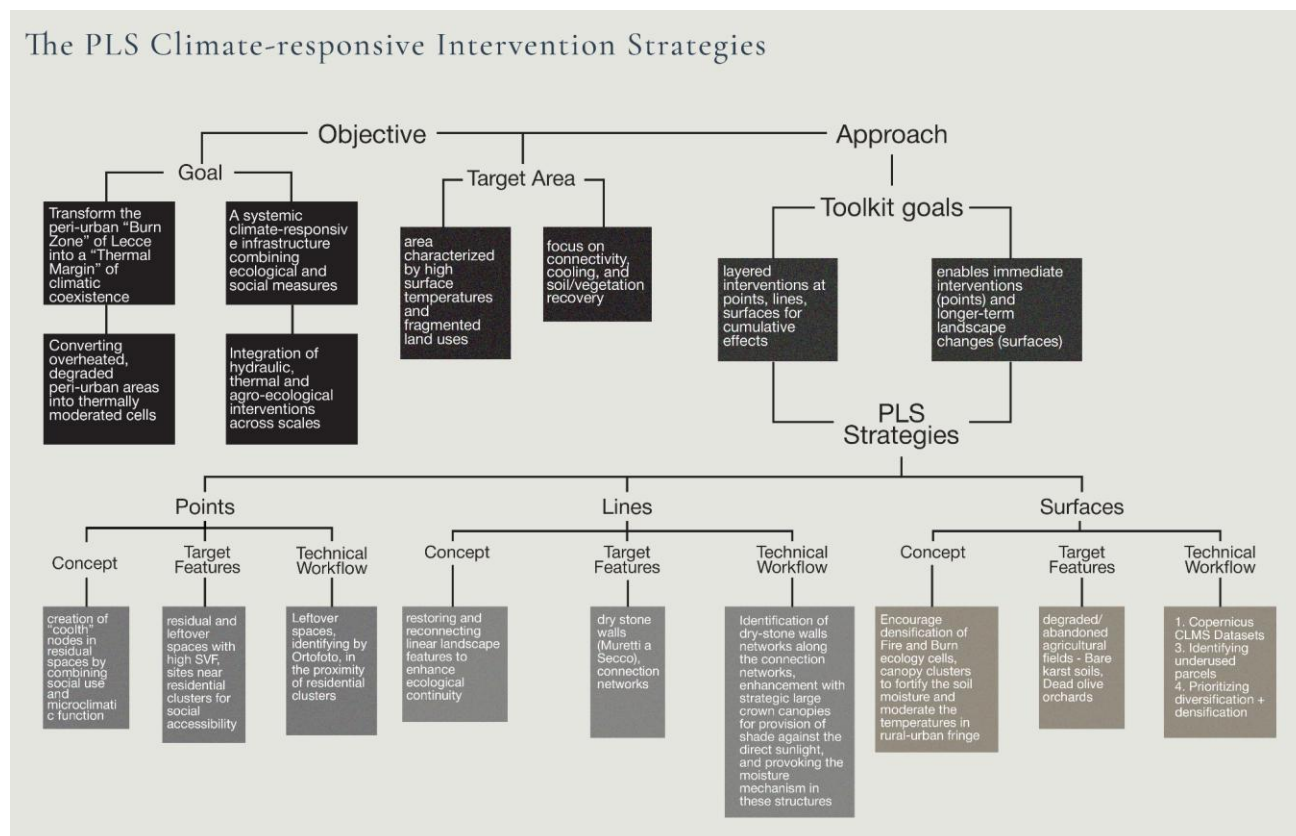
The three strategies of the PLS framework address three distinct conditions:

Table 10.1 The Point–Line–Surface Framework: Strategy, Spatial Logic, and RUTZ-Index Targeting

Strategy	Function	Spatial logic/target	RUTZ-Index targeting	Intervention typologies
POINT	Climate shelters and coolth nodes for vulnerable populations	Open public or residual brownfield spaces with high direct solar exposure, low or absent canopy presence, and proximity to residential clusters	Active Margin & Critical Fringe cells co-located with HRI Elevated/High census sections	Cistern-plazas, shaded micro-plazas, climate-shelter pavilions with <i>Morus nigra</i> canopy, water-evaporative surfaces
LINE	Ventilation, accessibility, and thermo-social corridors	Existing dry-stone wall network (muretti a secco) and rural road corridors threading the operational band	High wall density cells of the Active Margin; secondary and tertiary road network across Critical Fringe	Wall restoration, linear canopy tree-lines along walls and roads, shaded pedestrian/cycling routes, transit-stop shading
SURFACE	Agricultural densification and thermal commons	Thermally exposed bare karst surfaces, dry herbaceous abandoned parcels, and <i>Xylella</i> -affected abandoned olive orchards	F1, F2, and F4 ecology cells within the Active Margin and Critical Fringe	Heat- and drought-resistant species diversification (<i>Punica granatum</i> , <i>Ficus carica</i> , <i>Morus nigra</i>) inter-planted between existing olive linear formations; canopy densification on bare karst surfaces

The framework is non-prescriptive about quantity and location at the masterplan scale. It is prescriptive about logic: a Point intervention must respond to a measurable condition of solar exposure and demographic vulnerability; a Line intervention must reinforce an existing dry-stone wall or road corridor rather than create new ones; a Surface intervention must address a documented condition of agricultural collapse or thermal exposure with diversified species selection that combines cooling performance with ecological resilience to the specific Mediterranean threats the fringe faces. The PLS framework is the operative instrument through which the RUTZ Index becomes a design action.

Figure 10.1 The Point–Line–Surface (PLS) Framework: Conceptual Diagram



Note. The Point–Line–Surface framework shows the three intervention scales and their spatial logic across the operational peri-urban band (Active Margin and Critical Fringe)

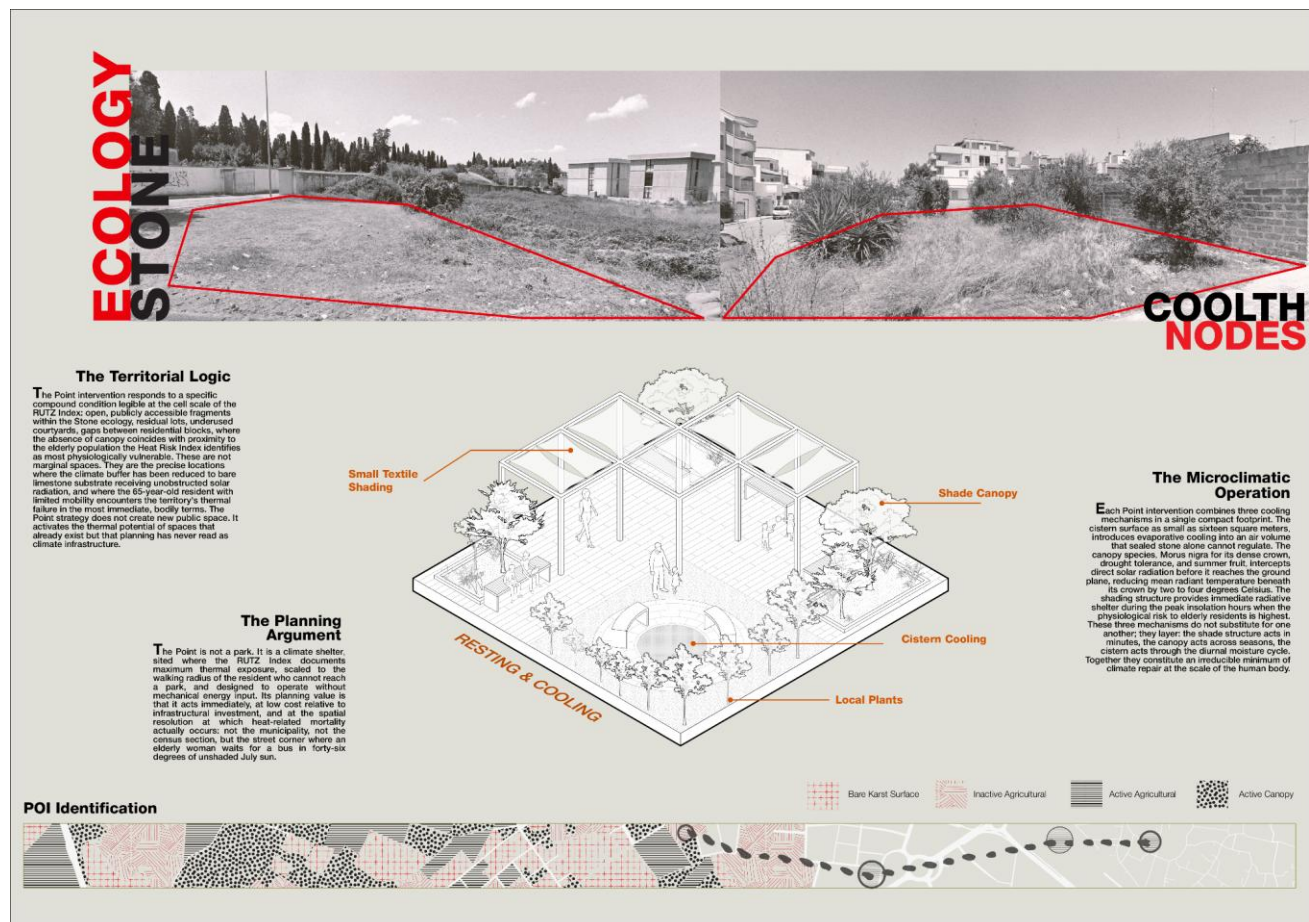
10.2.1 Point: Social Acupuncture and Climate Shelters

At the Point scale, the intervention acts like social acupuncture (Casagrande, 2020): small, targeted insertions of climate-mitigating microspaces in territories where solar exposure intersects with demographic vulnerability. The siting logic in the Lecce fringe responds to a specific compound condition: open, publicly accessible spaces, small plazas, abandoned lots, residual fragments at the meeting of residential blocks and through-roads — that are characterized by high direct solar radiation, low or absent canopy presence, and proximity to residential clusters housing the elderly cohort most physiologically vulnerable to heat. Querying the OpenStreetMap layers cross-referenced against the FISHNET_Master_Profile, the candidate sites are identifiable as cells in the Active Margin and Critical Fringe whose Building Surface Fraction is low ($BSF < 0.15$), whose Impervious Surface Fraction is moderate ($ISF 0.30–0.60$, suggesting paved or compacted ground rather than green surface), whose canopy fraction (from Copernicus TCD 2023) is below 5%, and which lie within proximity of residential blocks in census sections scoring ‘Elevated’ or higher on the Heat Risk Index. The main reason for the consideration of ISF was simply thermal, and that is the sensible heat transferring to the air above under extreme heat conditions.

The intervention typology proposed for these sites is the cistern-plaza, the shaded micro-plaza with canopy trees, and the climate-shelter pavilion (Maccabiani et al., 2025). Each

typology operates on a specific microclimatic principle. The cistern-plaza inserts a small water-collecting and evaporative surface, as compact as 16-40 m² — capable of cooling an adjacent air volume of approximately 2,826 m³ by 1°C through evaporative cooling alone (Qiu et al., 2013). The shaded micro-plaza uses canopy trees, with *Morus nigra* (black mulberry) as the species of choice for its dense crown, drought tolerance under deficit irrigation, and proven under-canopy temperature reductions exceeding 2°C (Orlandi et al., 2022); *Morus nigra* also produces edible fruit in summer, integrating climate function with social and economic value at the neighborhood scale. The climate-shelter pavilion is a small built canopy structure providing immediate radiative shelter for elderly residents during peak heat hours, ideally with a small water feature integrated into its base. The three typologies are not mutually exclusive: the canonical Point intervention combines all three in a small intervention footprint that responds to the specific geometric and demographic conditions of its site. A relief space, a cooling shelter just to sit and rest in the summer's baking sun.

Figure 10.2 Point Climate Shelter Prototype



Note. Prototype design for a Point intervention: cistern-plaza, fortified with large crown canopies, and climate-shelter pavilion for sitting and cooling relief. *Source: author's design proposal.*

The planning value of the Point intervention is that it acts immediately, at low cost relative to infrastructural investment, and at the spatial scale at which the elderly resident with limited mobility actually experiences the territory. A 65-year-old resident living on the

outskirts of the city, in an apartment block, cannot walk three kilometers to reach a park; she can walk 200 meters to a cistern-plaza at the corner of her street. The Point strategy responds directly to the section 8.4 finding that heat-vulnerable populations concentrate in the satellite towns and fractured zones where street-tree provision is minimal and that the climate shelter must therefore be brought to them rather than expected of them.

10.2.2 Line: Ventilation, Accessibility, and Thermo-Social Corridors

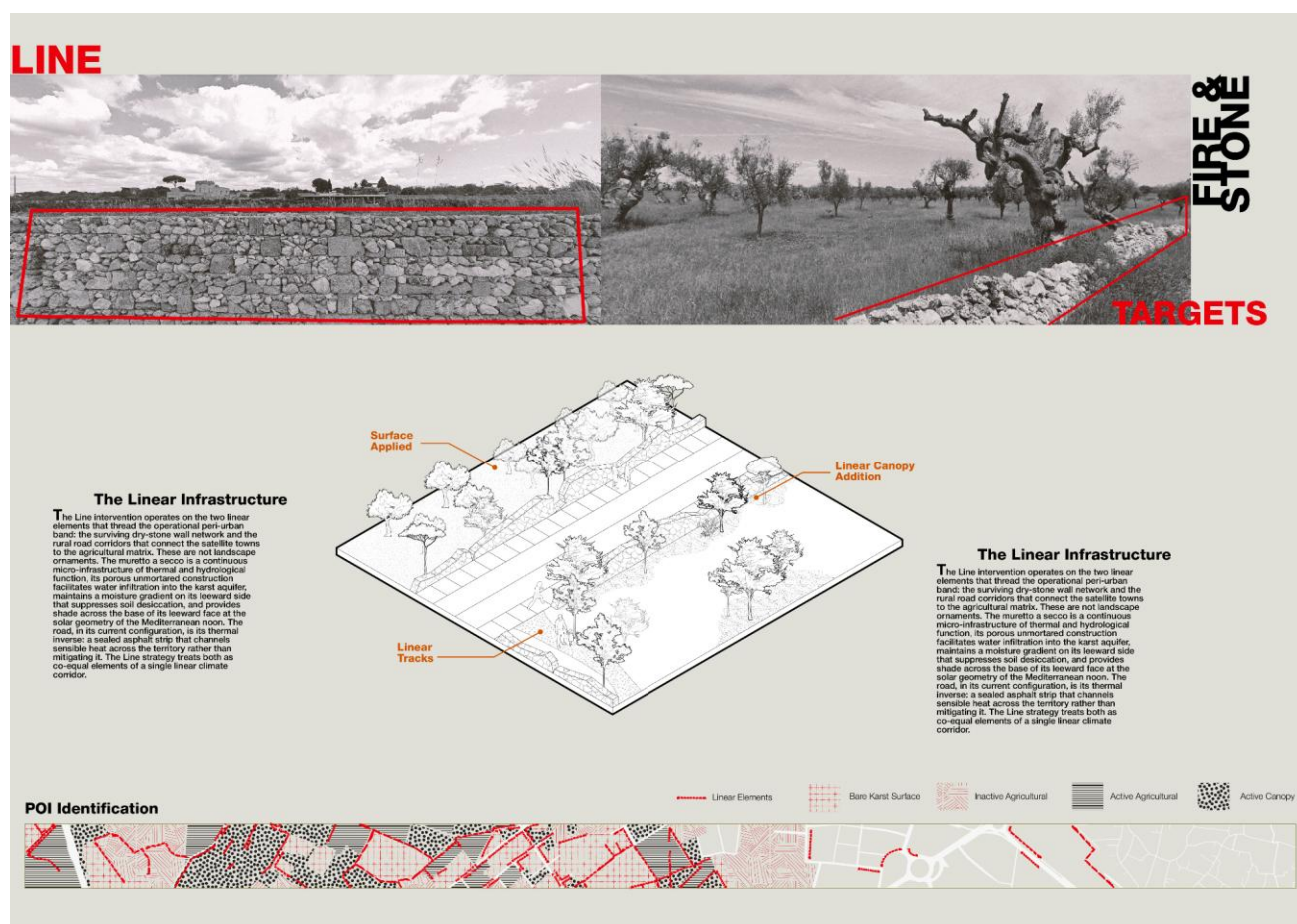
The Line strategy operates on the linear elements that thread the operational peri-urban band: the existing dry-stone wall network and the rural road corridors that connect the satellite towns to the agricultural matrix and to one another. The dry-stone wall and road networks alone form a Linear infrastructure dense enough to carry the strategy across the entire operational band. Restoring the walls and shading the roads is the thesis's Line strategy in full, where simply providing shade where residents move can provide cooling relief and address the thermal discomfort significantly.

The dry-stone wall network is the most thesis-specific element of the Line strategy. The built-verified muretto a secco dataset (Chapter 6) reveals the surviving network as a continuous infrastructure of thermal and ecological function: a porous micro-infrastructure that facilitates water infiltration into the karst aquifer, mitigates soil desiccation through the moisture gradient maintained on its leeward side, moderates diurnal thermal variation through the high thermal mass of local limestone, and provides shade across the base of its leeward wall at the solar geometry of the July noon (Pisano et al., 2022). Wall density at the cell level correlates positively with surviving canopy and negatively with summer LST anomaly in the Stone matrix, the spatial signature of the wall as functioning thermal infrastructure rather than agricultural relics. The Line intervention for the wall is restoration: repair of crumbling sections, replacement of fallen stones, and, critically, the strategic addition of linear canopy along the wall using heat- and drought-resistant species whose root systems do not threaten the wall foundation. The wall plus canopy combination is the operative Linear element of the Salento fringe. The placement would follow the logical buffer distance to allow the breeze to move into the territory.

The rural road network carries the second component of the Line strategy. The provincial and secondary road corridors that radiate from the satellite towns toward the agricultural interior are, in their current configuration, sealed, fragmented asphalt strips with negligible shading: a thermally hostile linear infrastructure that channels sensible heat across the operational band rather than mitigating it. The Line intervention for the road network is the cool route: linear canopy plantations along the road verge, shaded transit stops at intervals appropriate to non-motorized access, and where pedestrian and cycling infrastructure is present or could be inserted, the conversion of one lane of the road into a shaded, plant-buffered active-transport corridor. Cool routes reduce the unequal heat exposure of non-car users, who are more prone to heat-related discomfort (Wu & Shan, 2024), connecting the Point interventions (climate shelters) into a continuous, accessible network.

Where wall and road converge, where a road runs alongside a surviving muretto a secco network, the Line intervention will combine the two: wall restoration and canopy plantation on the rural side, cool-route conversion on the road side. This combined Linear element is the most ecologically and demographically productive instance of the strategy, restoring vernacular climate infrastructure while simultaneously addressing the daily mobility-and-exposure problem of the satellite-town resident. The Line intervention system is a two-way strategic answer to two ecological cells of our study, the Stone and the Fire ecologies, where the shadow is dead, the movement is no longer, the local landscape heritage is forgotten; there, the Line and following Surface strategy will be deployed.

Figure 10.3 Line Strategy: Wall and Road Corridor Prototype



Note. Prototype design for a Line intervention along a representative stretch of corridor where road and surviving muretto a secco networks converge: wall restoration, linear canopy planting, and cool-route conversion shown in the isometric visual. Source: author's design proposal.

10.2.3 Surface: Agricultural Densification and Thermal Commons

The Surface strategy addresses the most extensive territory in the intervention domain: the thermally exposed bare karst surfaces, the dry herbaceous abandoned parcels, unfinished construction and dumping sites, and the Xylella-affected abandoned olive orchards that together constitute the F1, F2, and F4 sub-classes of the Fire ecology composite. These cells, distributed across the Active Margin and the Critical Fringe, are the surfaces where the buffer mechanism has most completely failed and where the territorial cooling capacity

of the fringe must be reconstituted from the ground up, as the sub-typology composition documented in Figure 7.3h (section 7.2) makes spatially explicit. The strategy proceeds through two operations applied jointly: diversification (introducing heat- and drought-resistant species not currently present in the territory) and densification (increasing canopy coverage on bare surfaces and increasing tree density on abandoned orchards to enhance the moisture mechanism in the surface soil).

The Salento agricultural landscape historically operated as an olive monoculture, a configuration that the *Xylella fastidiosa* epidemic has revealed as climatically and ecologically vulnerable. The diversification operation introduces a small palette of species selected for three converging criteria: heat tolerance and drought resilience under the Csa Mediterranean climate; canopy density and evapotranspiration performance for cooling function; and ecological complementarity with the surviving olive groves, the new species are planted alongside, with the use of line-distancing between the rows of olive plants and strategically mixing with other species to prevent the transmission of *Xylella*. Three species form the core diversification palette: *Punica granatum* (pomegranate), *Ficus carica* (fig), and *Morus nigra* (black mulberry). Each is native or naturalized to the Mediterranean basin, each tolerates the shallow calcareous soils of the Salento karst, and each performs measurable canopy cooling under deficit irrigation conditions (Tarantino et al., 2021; Orlandi et al., 2022). The palette is intentionally small: a complex species list would compromise the maintenance economy that the Surface strategy depends on, and the three species together cover the structural functions (canopy density, drought tolerance, soil stability) the strategy requires.

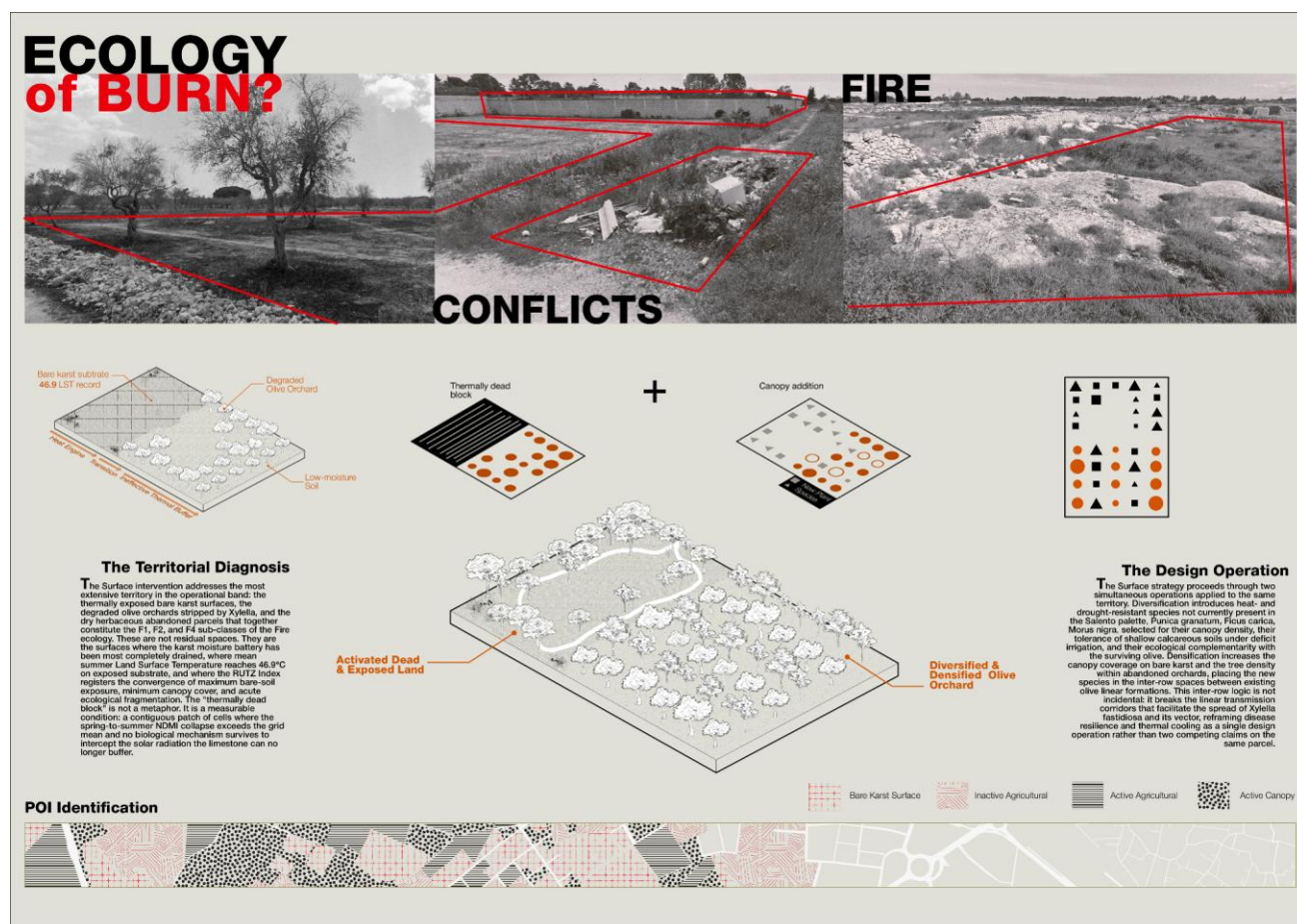
Densification: bare karst and abandoned orchard logics

Densification operates differently on the two substrate conditions that the Surface strategy addresses. On thermally exposed bare karst surfaces, the F2 sub-class operation is canopy reconstitution: plantation of mixed canopy species (the three-species palette plus the existing olive where it survives) at the density appropriate to the soil moisture-holding capacity and the shallow calcareous substrate. The objective is to cover the bare karst with a continuous to semi-continuous canopy that intercepts direct solar radiation, sustains shaded soil moisture, and re-establishes the evapotranspirative cycle that the karst loses when its vegetation is stripped. Studies in comparable agroforestry settings have demonstrated LST reductions of up to 19.35 °C under a structured canopy compared to a bare-soil baseline (Yuan et al., 2023). The Lecce fringe will not achieve that maximum under the Csa drought ceiling, but reductions of 4–6 °C at the canopy surface are documented in analogous Mediterranean studies and would be sufficient to shift the operational band's summer LST from the current 45.5 °C mean toward the 41–42 °C ceiling at which heat-stress vulnerability declines substantially.

On abandoned olive orchards, the F1 sub-class densification operates with an additional structural constraint: the existing olive groves are arranged in linear formations, a configuration historically necessary for mechanical harvest and irrigation but now structurally exposed under *Xylella* infection because the linear arrangement provides an

unobstructed transmission corridor for the pathogen's transfer. The densification operation for abandoned orchards therefore introduces the diversification species not in alternative blocks but in the inter-row spaces between the existing olive lines, breaking the linear continuity that facilitates *Xylella* spread while increasing canopy density and species diversity in the same operation (Ali et al., 2021). The inter-row densification logic is the thesis's specific contribution to the Surface strategy: it reframes *Xylella* resilience and thermal cooling as a single design operation rather than two competing claims on the same territory.

Figure 10.4 Surface Strategy: Diversified Orchard / Bare Karst Densification Prototype



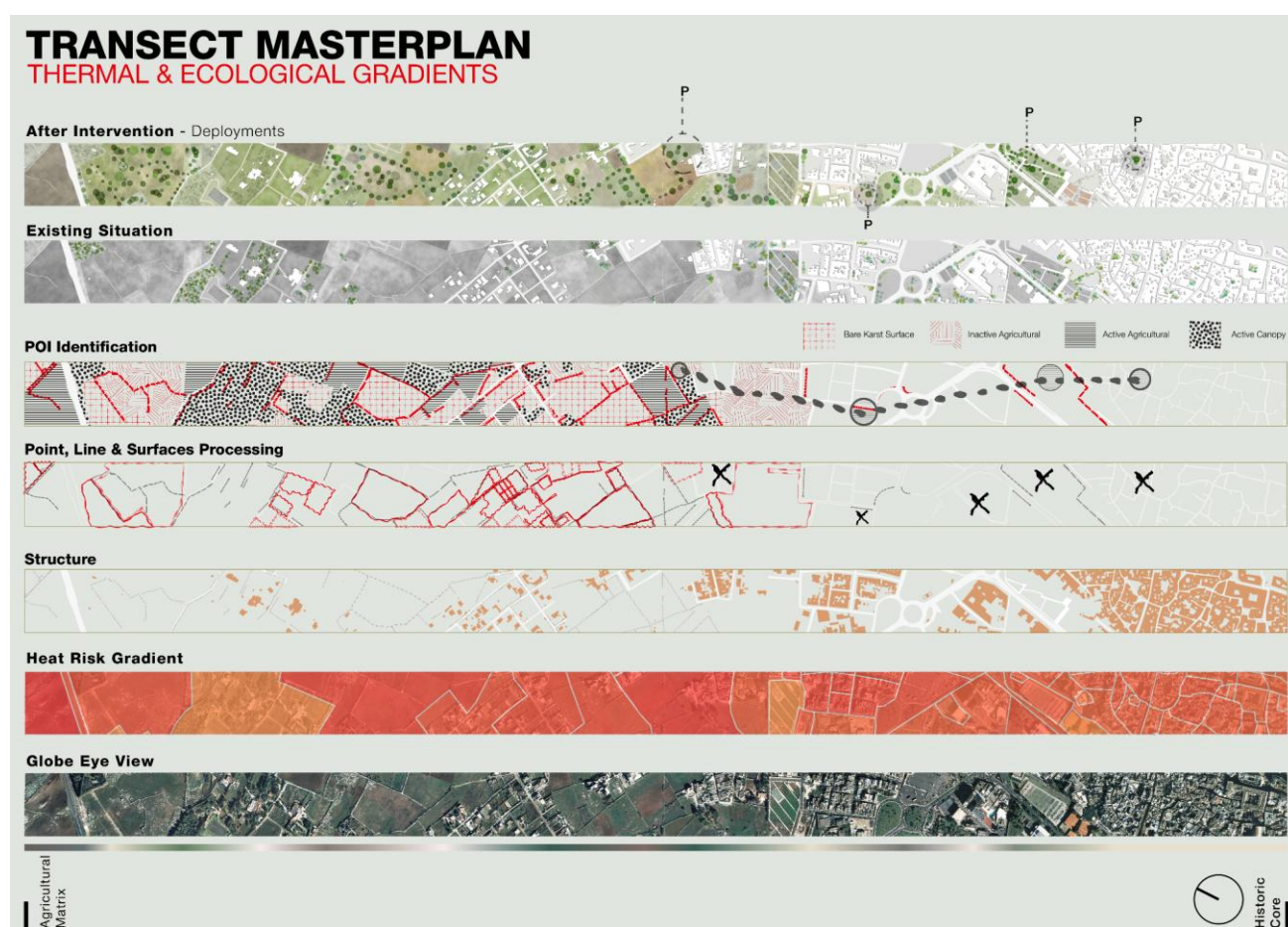
Note. Prototype design for a Line intervention along a representative stretch of corridor where road and surviving muretto a secco networks converge: wall restoration, linear canopy planting, and cool-route conversion shown in the isometric visual. Source: author's design proposal.

Selected densified surfaces, at the scale of an abandoned orchard or a contiguous bare-karst expanse of two to five hectares, can be designated thermal commons, publicly accessible territories whose cooling function operates as collective ecological infrastructure for the residents inhabiting the zones of collapse. The thermal commons concept ties the Surface strategy to the demographic argument of Chapter 8: a densified surface adjacent to a residential block becomes simultaneously a cooling source for the surrounding territory, a maintenance employment opportunity for the local population, and a publicly accessible green space for the elderly residents whose heat exposure the HRI quantifies. The Surface strategy is, in this sense, the most ambitious of the three PLS scales;

it is also the most spatially extensive and the most consequential for the long-term thermal performance of the buffer.

Figure 10.5 assembles the three intervention scales into a single transectual reading: the 4.05-kilometer section, the transect as site of prototype, rendered as six stacked analytical bands, existing situation, PLS processing, structural framework, heat risk gradient, and the projected post-intervention landscape, making legible in a single frame the territorial logic that connects the isolated Point shelter in the built fabric's unused open spaces to the densified Surface on the karst plateau beyond it. All the layers are the study's discussions, designs, analyses, and logics that live as a complete sequence of transects, which illustrate the processes for the final transect master plan.

Figure 10.5 *Transectual Masterplan (the six-band gradient sheet)*



Note. Note. Six analytical bands read the same 4.05-kilometer transect from Agricultural Matrix (left) to Historic Core (right), stacking the thesis's diagnostic and prescriptive registers into a single territorial section. From bottom to top: the satellite context (Globe Eye View); the summer Heat Risk Gradient confirming the reverse-UHI signature across the section; the structural framework of parcels, walls, and road corridors that carry the Line strategy; the Point, Line, and Surface processing layer identifying intervention sites within the operational peri-urban band; the existing situation as orthophoto; and the projected post-intervention landscape, in which the three PLS strategies have been applied to the cells the RUTZ Index identified as the priority domain. The color bar below the globe eye orthophoto encodes the dominant ecology at each position along the transect in a gradient visualization graph. The thesis measured in degrees Celsius, this figure proposes in trees, walls, and shade. Source. Author's design proposal and territorial analysis. *Data & databases:*

10.3 The RUTZ Index as Decision Support: Adapted for Planners

The RUTZ Index, as constructed in Chapter 9 and as the operative analytical instrument of the design strategy above, is calibrated to the resolution and the analytical demands of the environmental- and landscape-grade morphological and ecological analysis the thesis performs. It is not, in this state, a decision-support tool for the planning practitioner. The translation step that this section proposes is the production of an Index-derived planning grade for each cell of the operational peri-urban band, expressed in a format that aligns with the planning vocabulary of the Piano Urbanistico Generale (PUG) of the Comune di Lecce and the eight surrounding municipalities and with the cartographic conventions of the Piano Paesaggistico Territoriale Regionale (PPTR) of the Regione Puglia.

Three planning grades are proposed, derived directly from the RUTZ Index calibration and the HRI overlay (Chapter 8). Grade A (Priority Restoration) marks cells in the Active Margin or Critical Fringe whose composite RUTZ score is highest and which sit within HRI Elevated or High census sections, the cells where the buffer mechanism is failing fastest and where the population most exposed to heatwave risk lives. Grade A cells are the priority targets of all three PLS strategies and should be the first sites of intervention in any PUG-scale implementation. Grade B (Buffer Maintenance) marks cells in the Active Margin and Critical Fringe whose RUTZ score is moderate and which sit within Moderate-Elevated HRI sections; these are cells where the buffer is still functioning but is at risk of trajectory decline as the Active Margin moisture indices continue to deteriorate. Grade B cells are appropriate for Line and Surface interventions focused on consolidation and trajectory reversal. Grade C (Protection) marks all cells in Classes 1 and 2 of the peri-urban classification (Rural Matrix and Margin Approach), the deep buffer territories where intervention is not required but where regulatory protection against conversion to peri-urban development is the appropriate planning instrument. Also, the Shadow ecology dominant ecology cells are excluded from intervention strategies due to their normal cooling behavior. Grade C cells are the candidate territories for landscape protection designation under the PPTR's existing categories of 'paesaggio rurale' and 'ambito paesaggistico'.

The three-grade structure aligns the analytical resolution of the RUTZ Index with the operational vocabulary of Italian planning regulation. The PUG can read Grade A cells as priority intervention zones for which design proposals using the PLS framework qualify for accelerated approval and partial public co-funding under regional climate adaptation budgets. Grade B cells become the natural sites of the regional Programma di Sviluppo Rurale (PSR) under the European agricultural funding framework, with the agroforestry densification operations of the Surface strategy qualifying directly for the Misura 8 funding for forestry and silvicultural investments. Grade C cells become the protected territory whose conservation generates the climate-buffer benefit that the operational band cannot

fully replace. The planning instrument's three grades are not graphical decoration; they translate the index's analytical, environmental, and morphological character into the language of the funding mechanisms that can actually implement the strategy.

10.4 Integration with the Piano Urbanistico Generale

The Piano Urbanistico Generale (PUG) of the Comune di Lecce, currently in extended drafting under the regional Legge Regionale, is the proper administrative vehicle for the implementation of the RUTZ-informed design strategy proposed above. The PUG operates at the scale of the municipality but, under Italian planning law, is coordinated with the neighbouring municipalities' equivalent instruments through the regional planning framework. For the nine-municipality study area, the integration logic is therefore two-tiered: the PUG of each comune accommodates the Grade A and B intervention domains within its own boundary, while the regional PPTR provides the coordinating framework for Grade C protection across municipal boundaries.

Three policy integration mechanisms are proposed. The first is the inclusion of the RUTZ-derived planning grades as a mandatory analytical layer in the PUG's quadro conoscitivo, the foundational analytical document on which the PUG's zoning decisions are based. The RUTZ classification, expressed as the three-grade map and accompanied by the operational-band thermal and ecological summary, becomes a required input alongside the existing morphological, hydrological, and ecological data that the PUG already incorporates. This integration does not require a regulatory change: the PUG's existing analytical structure accommodates additional analytical layers without modification, and the RUTZ Index simply joins the established suite. The second mechanism is the formal designation of the Active Margin and Critical Fringe cells as a new zoning category, the thermal transition zone, with regulatory provisions that combine protection against further peri-urbanisation with active intervention permission for the PLS strategy typologies. The third mechanism is the establishment of a permanent monitoring protocol, executed annually by the regional environmental authority (ARPA Puglia), that re-runs the RUTZ analysis on the most recent Landsat acquisition and reports trajectory change in the operational band against the baseline established by this thesis. The monitoring protocol does not require a new institution; it requires the integration of the analytical workflow into ARPA Puglia's existing environmental reporting cycle.

10.5 Limitations: Where the Model Under-Performs and Why

The analytical instrument proposed here has limitations that are intellectually honest to surface. The first is temporal: the RUTZ Index is calibrated against a four-year, twelve-scene satellite record (2015, 2018, 2021, 2025), and its conclusions therefore describe a present-

tense buffer condition rather than a long-term trajectory. The seasonal inversion finding is robust across the four available years, but the medium-term trend in the operational band's moisture indices, the trajectory that justifies intervention urgency rests on a six-to-ten-year analytical window that is shorter than the climate-adaptation planning horizon the strategy addresses. Replication of the analysis on a longer record (Landsat 5 archives extending to 1984, where available for the Salento) would strengthen the trajectory claim without revising the framework's foundations.

The second limitation is spatial. The 100-metre fishnet resolution at which the RUTZ Index operates is the minimum resolution at which morphological and thermal data can be integrated without misleading precision, but it is coarser than the resolution at which the PLS interventions actually land. For example, a Line intervention runs along a wall or road that may bisect a fishnet cell rather than fill it. The translation from the cell-scale RUTZ classification to the parcel-scale intervention requires finer data availability and analytical pass at each candidate site, drawing on cadastral data and orthophoto interpretation that the index does not itself provide. The index identifies the target cells; the design process operates at a resolution below. Moreover, the lack of accessibility to proper 3-dimensional data layers, such as Digital Surface Model (DSM), could significantly provide precise data regarding the tree canopies and the buildings' height data.

The third limitation is methodological. The deep learning canopy detection workflow (section 5.5) revealed that bare Pietra Leccese limestone is spectrally confused with sparse vegetation under standard object-detection models calibrated for non-Mediterranean contexts. The Copernicus Tree Cover Density layer used in the analysis is the correct alternative; it operates at pixel scale and resolves the spectral confusion that object detection cannot, but it is not native to the Salento limestone landscape and carries its own potential systematic error. Validation of the TCD-derived canopy figures against ground-truth field measurements in selected representative cells is the appropriate next step, beyond the scope of the present thesis.

The fourth limitation is institutional. The PLS framework presumes that the implementing institutions, the municipal administration, the Regione Puglia, and the regional agricultural authorities have the analytical capacity and the budgetary mandate to execute the strategy at the territorial scale. The Italian planning system has the regulatory tools to do so, as the PPTR and the PUG demonstrate; whether the operating budgets and the institutional alignment will follow is a question this thesis cannot answer. The strategy is correct on the analytical merits and aligned with the existing regulatory framework. Its implementation depends on political and budgetary decisions that operate at a scale beyond the thesis's reach.

These limitations do not undermine the strategy; they identify the trajectory of work that the thesis opens but cannot complete. Each limitation, the temporal record, the spatial resolution, the current data availability and accessibility, the methodological calibration, the institutional implementation, corresponds to a research continuation path that the doctoral

program to which this thesis is positioned as a pathway will be capable of pursuing. What the thesis contributes is the analytical foundation on which those continuations can stand: an instrument calibrated to the resolution of the territory that produced it, a strategy aligned with the regulatory and material vocabulary of the Salento, and an empirical record demonstrating that the climate buffer is still partly functional in the cells where intervention can act. The Lecce peri-urban fringe is not yet what it could be. It is no longer what it was. The PLS strategy proposes the shape of what comes next.

Chapter II

CHAPTER 11: Conclusion

This chapter does not summarize the thesis. The analytical chapters have already done that. What the conclusion does is name what the thesis changes in how the Lecce peri-urban fringe is seen, measured, and governed and in doing so, account for each commitment made at the opening. Four research questions were posed. Four working hypotheses were advanced. The seven chapters of empirical work that follow them constitute the audit. This chapter reads that audit back.

11.1 Summary of Contributions: Theoretical, Methodological, Empirical

The thesis set out to answer four research questions about a territory that existing planning instruments had consistently failed to read with the resolution its thermal function demands. The answers are now available, grounded in the evidence assembled across Chapters 6 through 10. Each research question and working hypothesis is addressed in turn below, before the contributions that emerge from the full body of work are stated explicitly.

Research Question 1 – Thermal Buffer Performance

To what extent does the rural–urban transition zone of Lecce function as a measurable thermal buffer, and how does its buffer capacity vary across the seasons and across the three ecological typologies?

Working Hypothesis 1 – CONFIRMED. The thermal relationship between the three ecologies of Lecce is not fixed. The seasonal inversion, documented across all four years of the satellite record (2015, 2018, 2021, 2025) using twelve Landsat scenes, holds without exception. In spring, Fire cells register the highest mean Land Surface Temperature; in summer, Stone cells register the highest. The spring-to-summer sign reversal in the ecology-level LST ranking is the most robust empirical finding of the study: it holds in every L8-only year independently, at effect sizes that ANOVA confirms are not statistical noise ($\eta^2 = 14.3\%$ in summer, 18.8% in spring). The buffer is real, seasonal, and measurable at hectare resolution.

The mechanism, as section 7.7 establishes, is moisture-driven: the Stone karst matrix charges its moisture reserve through the winter and releases it through spring evapotranspiration, running the coolest of the four ecologies during the spring shoulder season. As the Csa summer drought exhausts that reserve, the stone surface, high albedo but no longer evapotranspiring, becomes the hottest terrain in the study area. Fire cells, conversely, carry the low-albedo impervious surfaces that peak in spring but whose sealed configuration concentrates heat in the spring sun while their low moisture reserve leaves them relatively flat across the summer record. The inversion is not a paradox once the mechanism is understood. It is the systematic, repeatable consequence of the karst moisture battery operating on a Mediterranean phenological clock. The buffer is not a place. It is a season. And the season in which it functions, spring, is the season in which protecting the Stone ecology's moisture-holding capacity matters most for the urban thermal management of Lecce.

Research Question 2 — Classification Framework Adequacy

What do the documented limitations of existing spatial classification systems, Local Climate Zones, Spacematrix, and FRAGSTATS-based fragmentation analysis reveal about their capacity to resolve the morphological and thermal complexity of Lecce's peri-urban fringe, and does a composite index built on adapted versions of their component logics succeed where the source frameworks, applied independently, do not?

Working Hypothesis 2 — CONFIRMED. Standard LCZ classification systematically misclassifies the transition zone cells. The published evidence— a 32% classification accuracy for sparsely built LCZ 9 (Demuzere et al., 2019), direct documentation of LCZ method sensitivity in the Lecce case by Pappaccogli et al. (2025), and the structural argument that LCZ's neighborhood-scale homogeneity assumption cannot hold in the heterogeneous fringe mosaic — is confirmed both by the literature and by the RUTZ Index's demonstrated performance. The RUTZ classification explains 14.3–18.8% of summer LST variance (§9.3) using only morphological, ecological, fragmentation, and wall-density inputs — zero thermal data. An instrument built blind to temperature achieves an effect size of this magnitude because it resolves the fringe's spatial structure at the 100-meter resolution at which thermal differentiation actually operates. The LCZ framework, by design, cannot.

The most direct evidence for this finding is the 83.4% invisibility of the Fire ecology to Urban Atlas 2021 (§7.2, §9.4): the standard European reference classification sees 129.94 hectares of the abandonment and stalled-construction territory that the RUTZ multi-source cross-validation pipeline reveals as 780.64 hectares. Nearly five-sixths of the territory most directly implicated in the thermal argument is invisible to the classification system that planning authorities across Europe rely on for spatial evidence. This is not a calibration error in the RUTZ pipeline. It is a structural limit of any classification that cannot integrate the Copernicus ploughing indicator, crop-type change detection, and a hand-verified dry-stone wall network into a single composite assessment. The RUTZ Index exists, in large measure, to fill precisely this gap.

Research Question 3 — Population Heat Exposure

Which populations within the Lecce urban system are most exposed to heatwave risk, and where does the convergence of high population density, low tree cover, and elevated Land Surface Temperature concentrate that exposure across the city and its satellite towns?

Working Hypothesis 3 — CONFIRMED. The Heat Risk Index reveals that heat exposure concentrates structurally in the satellite municipalities rather than the historic urban core. Six out of nine towns return a mean composite HRI of 9.66 against Lecce city's 9.33, a gap consistent across all six without exception (§8.2.3). The Lecce historic core is simultaneously the least thermally exposed municipality on average and the location of the study area's highest individual HRI value (11.36), reflecting the wide internal heterogeneity produced by the city's mid-twentieth-century expansion neighborhoods. The hypothesis's specific prediction that the municipalities combining the highest surface temperatures and the most complete canopy deficit would rank highest on the HRI despite their smaller absolute populations is confirmed by Lequile (highest mean HRI, 9.98; lowest population

density, 825 persons/km²) and Surbo (second highest mean HRI, 9.85; most complete canopy absence, 98.3% TCD Lacking).

The demographic dimension of this finding, documented in sections 8.3 and 8.4, deepens its planning significance beyond what the HRI alone expresses. The satellite towns recording the highest HRI values are also the municipalities ageing fastest: Cavallino (+2.59 percentage points of elderly share between 2019 and 2024), Surbo (+2.33pp), and Lizzanello (+2.19pp) are simultaneously the highest-risk and the fastest-ageing territories in the study area. Experimental physiological research establishes that elderly women, who constitute 57.16% of the study area's 65+ cohort, lose thermoregulatory capacity at lower temperature-humidity combinations than men of equivalent age (Leach & Kenney, 2024). The thermal geography of the Lecce fringe is, in this reading, also a geography of differential mortality risk: the territory where the buffer is failing most rapidly is the territory where the population most physiologically vulnerable to its failure is concentrating. The HRI makes this convergence legible at the scale of the census section. That legibility is a precondition for any intervention program that takes heatwave mortality seriously as a planning objective.

Research Question 4 – Critical Urban Geography Reading

What conflictual coexistences are legible in Lecce's peri-urban fringe, and how do these spatial conflicts constitute the three ecological systems that the RUTZ Index classifies quantitatively?

Working Hypothesis 4 – CONFIRMED. The RUTZ Index's composite metric signature in each 100-meter cell is interpretable as a record of one of three co-present ecological logics, the Stone, the Fire, the Shadow. The quantitative classification and the critical territorial observation are mutually verifying: where the index assigns the Fire, the cross-validated multi-source pipeline confirms abandonment, stalled construction, and ecological residue in precise spatial correspondence with what the critical reading of the fringe as a contested metabolic zone expects. Where the index assigns the Stone, the thermal record confirms the limestone material's regulating role in degrees Celsius per cell, season by season. The three ecologies are not administrative polygons. They are metabolisms. Stone absorbs and holds across centuries of lithic continuity. Shadow breathes and cools through what the Xylella epidemic and agricultural abandonment have not yet destroyed. Fire burns and stalls at the edge of a debt cycle that planning has not yet named. The quantitative instrument and the critical reading speak the same spatial language about the same territory.

This fourth finding is the one that makes the thesis more than a measurement exercise. The RUTZ Index could have been presented as a remote-sensing product, a classification raster with a validation statistic. What the critical geography reading adds is interpretive depth: the understanding that the fringe's thermal pathology is the surface expression of a territorial condition produced by conflicting economic, ecological, and planning logics that operate simultaneously across the same 100 metres. The sealed villa driveway and the surviving muretto a secco are not adjacent land uses in an administrative register. They are adversarial metabolisms in a territorial argument whose outcome, for the urban climate of Lecce in 2030 and 2040, is still open.

Contributions

Three distinct orders of contribution emerge from the body of work.

The theoretical contribution is the operationalization of the peri-urban fringe as a climate buffer — not as a metaphor or a planning aspiration, but as a measurable territorial condition with quantified thermal performance. The thesis demonstrates, empirically, that the buffer mechanism operates seasonally and ecologically rather than spatially: it is not a zone that insulates by its location but a metabolic system whose insulating capacity depends on the seasonal moisture charge of its stone-and-soil matrix. This reframes the planning question. The question is not where to draw a protection boundary but when the buffer function is most at risk of failing — and the answer, confirmed by the RUTZ thermal validation, is the spring shoulder season, when the moisture reserve that drives the cooling function is still present and still destroyable by one more speculative conversion.

The methodological contribution is the RUTZ Index itself: a composite instrument that integrates five sub-scores — built density, impervious fraction, ecological isolation, dry-stone wall network density, and ecology composition — into a continuous, cell-level gradient calibrated to the specific morphological and ecological conditions of the Mediterranean semi-arid peri-urban fringe. The index is validated against an independent thermal record across four years and twelve Landsat scenes, achieving statistically significant predictive performance ($r = -0.14$ to -0.27 , summer; $r = +0.07$ to $+0.25$, spring; all $p < 0.001$) without any thermal input in its construction. The sensitivity analysis (§9.6) demonstrates that this validated performance is robust to the removal of any single sub-score: the operational intervention domain (Active Margin + Critical Fringe, 2,469 cells) retains 87.4-91.3% of its membership under perturbation. The index is not the only possible instrument for this territory. It is the first instrument designed specifically for it, with a transparent construction and a verifiable validation record.

The empirical contribution is the first systematic multi-year, multi-season thermal and morphological characterization of the Lecce peri-urban fringe at hectare resolution: twelve Landsat scenes, four ecological typologies, five peri-urban gradient classes, nine municipalities, 1,784 census sections, 8,625 cells. The seasonal inversion of the ecology thermal ranking, Stone hottest in summer, Fire hottest in spring, is documented here for the first time as a quantified, spatially resolved, multi-year finding rather than an anecdotal observation from a single scene. The 83.4% invisibility of the Fire ecology to the standard European classification (Urban Atlas 2021) is documented here for the first time as a specific, auditable number derived from a multi-source cross-validation pipeline. These empirical findings do not depend on the RUTZ Index to have meaning. They are contributions to the knowledge of the Lecce fringe that stand independently of any particular classification instrument.

11.2 The RUTZ Index as a Replicable Framework: Beyond Lecce

The RUTZ Index is designed for the Lecce fringe. Its indicator selection, the dry-stone wall density sub-score, the Copernicus-calibrated ecology composition, the Jenks classification of the composite score against a territorial study area fishnet reflects specific choices made in response to the specific conditions of the Salento karst. The question of replicability is therefore not a question of whether the same numerical instrument can be applied unchanged to another Mediterranean fringe city. It is a question of whether the underlying architecture is transferable: whether the principle of compositing morphological density, ecological fragmentation, vernacular infrastructure, and land-cover composition into a single cell-level gradient produces interpretable, thermally validated output in other contexts.

The architecture is transferable. The five sub-score families — density, sealing, isolation, vernacular infrastructure, ecological composition — are present, in some form, in every Mediterranean fringe territory. The specific indicators that operationalize each family will differ: the muretto a secco is a Salento vernacular; the acequias of Valencia, the terraced dry-stone walls of the Cinque Terre, and the traditional field boundaries of the Tuscan mezzadria landscape each provide an analogous vernacular infrastructure sub-score that a RUTZ-adapted pipeline could compute from the same data sources. The Copernicus Crop Type raster and the High-Resolution Layer suite are pan-European datasets available at 10-metre resolution for any study area on the continent. The Landsat thermal pipeline is global. A RUTZ application to the peri-urban fringe of Bari, Catania, or Athens requires a site-specific vernacular infrastructure dataset and a recalibration of the Jenks classification to the local morphological distribution, two investments that a graduate research programme or a regional planning authority could make in a single project cycle.

The proposition at the center of the PhD proposal that this thesis is positioned to support Governing the Thermal Margin and Peri-urban interfaces, is precisely this replication. The contribution of a doctoral program to the RUTZ framework would be the cross-context validation the thesis's single case study cannot provide: systematic application to two or three comparable Mediterranean fringe cities with different karst substrates, different agricultural histories, and different planning governance contexts, testing whether the seasonal inversion and the peri-urban gradient pattern are Lecce-specific findings or expressions of a structural Mediterranean fringe behavior that the single Lecce case can identify but cannot generalize. The thesis is, in this sense, complete as a thesis, it answers the four research questions it posed and incomplete as a research program, which is exactly the position a well-structured MSc thesis should occupy.

11.3 Final Reflection

On the 24th of July 2022, the countryside around Lecce burned hotter than the city itself. That observation, which opens Chapter 1, is where this thesis began. It ends in the same territory, but with a different vocabulary for what was observed. The historic core was not

simply cooler. It was cooler because of the material intelligence of the Pietra Leccese, its albedo, its thermal mass, its water-shedding geometry and cooler because of the ecological condition of the fringe that surrounded it. The fringe that burned was burning because the moisture reserve of the karst matrix had been exhausted, because the olive canopy that once sustained that reserve had been stripped by epidemic and abandonment, and because the planning system that might have defended both had not yet developed an instrument capable of seeing the connection between a dry-stone wall in Cavallino and a surface temperature reading in the historic center of Lecce.

The RUTZ Index is that instrument. It does not resolve the climate crisis. It does not replant the olive groves. It does not reverse the thirty years of speculative fringe development that produced the morphological condition it classifies. What it does is make legible, at the resolution at which the buffer mechanism actually operates, the territorial logic that connects the muretto a secco to the urban thermometer, the abandoned orchard to the heatwave mortality statistic, the ploughing indicator to the LST raster. Making that logic legible is the precondition for planning to act on it, not instead of political will, but before it, as the analytical foundation on which political will must rest if it is to act in the right place.

The Lecce fringe is not yet what it could be. It is no longer what it was. Between those two facts lies the territory this thesis has spent eight chapters measuring. What comes after this thesis, in the doctoral program that follows it, in the co-authored paper that accompanies it, in the planning documents of the municipalities whose vulnerability it quantifies, is the slow work of translation: from measurement to action, from index to intervention, from the abstract claim that the peri-urban fringe is a climate buffer to the specific, site-precise act of planting a *Ficus carica* between two rows of dead olive stumps in a field in Lequile and calling it, without irony, an act of planning.

References

References

- Aad, R., Zaher, N., Dawalibi, V., Balaa, R., Loukieh, J., & Nemer, N. (2025). The Application of Landscape Indicators for Landscape Quality Assessment: Case of Zahleh, Lebanon. *Sustainability*, 17(19). <https://doi.org/10.3390/su17198946>
- Adell, G. (1999). THEORIES AND MODELS OF THE PERI-URBAN INTERFACE: A CHANGING CONCEPTUAL LANDSCAPE.
- Albrecht, G., Sartore, G., Connor, L., Higginbotham, N., Freeman, S., Kelly, B., Stain, H., Tonna, A., & Pollard, G. (2007). Solastalgia: The Distress Caused by Environmental Change. *Australasian psychiatry: bulletin of Royal Australian and New Zealand College of Psychiatrists*, 15 Suppl 1, S95-8. <https://doi.org/10.1080/10398560701701288>
- Alfio, M. R., Balacco, G., Parisi, A., Totaro, V., & Fidelibus, M. D. (2020). Drought Index as Indicator of Salinization of the Salento Aquifer (Southern Italy). *Water*, 12(7), 1927. <https://doi.org/10.3390/w12071927>
- Alfio, M. R., Balacco, G., Dragone, V., & Polemio, M. (2024). A statistical approach for describing coastal karst aquifer: the case of the Salento aquifer (Southern Italy). *Acque Sotterranee - Italian Journal of Groundwater*, 13(4). <https://doi.org/10.7343/as-2024-759>
- Ali, B. M., Werf, W., & Oude Lansink, A. (2021). Assessment of the environmental impacts of *Xylella fastidiosa* in Puglia. *Crop Protection*, 142, 105519. <https://doi.org/10.1016/j.cropro.2020.105519>
- Allen, A. (2003). Environmental planning and management of the peri-urban interface: Perspectives on an emerging field. *Environment and Urbanization*. Allen, A. (2003) *Environmental planning and management of the peri-urban interface: perspectives on an emerging field. Environment and Urbanization*, 15 (1). pp. 135-148. ISSN 09562478, 15. <https://doi.org/10.1177/095624780301500103>
- Augé, M. (1995). *Non-places: introduction to an anthropology of supermodernity*. London; New York: Verso.
- Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H. R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabchenko, D., Schindler, C., & Michelozzi, P. (2008). Heat effects on mortality in 15 European cities. *Epidemiology*, 19(5), 711-719. <https://doi.org/10.1097/EDE.0b013e318176bfcd>
- Baldinelli, G., Bonafoni, S., & Rotili, A. (2017). Albedo Retrieval From Multispectral Landsat 8 Observation in Urban Environment: Algorithm Validation by in situ Measurements. *IEEE*

Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 10(10), 4504–4511. <https://doi.org/10.1109/JSTARS.2017.2721549>

Banham, R. (1971). *Los Angeles: The architecture of four ecologies*. Harper & Row.

Barletta, C., Capolupo, A., & Tarantino, E. (2022). Exploring the Potentialities of Landsat 8 and Sentinel-2 Satellite Data for Estimating the Land Surface Albedo in Urban Areas Using GEE Platform. In *Computational Science and Its Applications – ICCSA 2022 Workshops* (pp. 435–449). Springer International Publishing. https://doi.org/10.1007/978-3-031-10545-6_30

Barletta, C., Capolupo, A., & Tarantino, E. (2023). Extracting Land Surface Albedo from Landsat 9 Data in GEE Platform to Support Climate Change Analysis. *Geomatics and Environmental Engineering*, 17, 35–75. <https://doi.org/10.7494/geom.2023.17.6.35>

Barletta, C., Capolupo, A., & Tarantino, E. (2024). Estimating Urban Growth from Landsat 8 Data Using Post-classification and Albedo Change Analysis in GEE Environment. In *Computational Science and Its Applications – ICCSA 2024 Workshops* (pp. 185–200). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-65282-0_12

Berghauser Pont, M., & Haupt, P. (2010). *Spacematrix: Space, density and urban form*. NAI Publishers.

Berghauser Pont, M., & Haupt, P. (2023). *The mathematics of form*. Delft University of Technology.

Buxton, M., Tieman, G., Bekessy, S., Budge, T. M., Mercer, D., & Coote, M. (2006). *Change and continuity in peri-urban Australia, state of the peri-urban regions: a review of the literature*. RMIT University. <https://doi.org/10.25439/rmt.27337518.v1>

Casagrande, M. (2020). From Urban Acupuncture to the Third Generation City. In R. Roggema (Ed.), *Nature Driven Urbanism* (pp. 131–153). Springer International Publishing. https://doi.org/10.1007/978-3-030-26717-9_7

Clément, G. (2022). *Manifesto of the third landscape* (J. Jones, Trans.). Trans Europe Halles.

Clément, G. (2004). *Manifeste du Tiers paysage*. Éditions Sujet/Objet.

Copernicus Land Monitoring Service. (2022). *High Resolution Layer Tree Cover and Forests – Forest Type 2021, Europe [Dataset]*. European Environment Agency. <https://land.copernicus.eu/en/products/high-resolution-layer-forests-and-tree-cover>

Copernicus Land Monitoring Service. (2023). *Urban Atlas Land Cover/Land Use 2021 (vector), Europe, 3-yearly* [Dataset]. European Environment Agency. <https://doi.org/10.2909/05ae1ee1-e550-4e66-b74d-4926322d981a>

Copernicus Land Monitoring Service. (2024). *High Resolution Layer Croplands – Crop Types 2023 (raster 10 m), Europe, yearly* [Dataset]. European Environment Agency. <https://land.copernicus.eu/en/products/high-resolution-layer-croplands/crop-types-2023-raster-10-m-europe-yearly>

Copernicus Land Monitoring Service. (2024). *High Resolution Layer Croplands – Ploughing Indicator 2023 (raster 10 m), Europe, yearly* [Dataset]. European Environment Agency. <https://land.copernicus.eu/en/products/high-resolution-layer-croplands>

Copernicus Land Monitoring Service. (2024). *High Resolution Layer Tree Cover and Forests – Tree Cover Density 2023 (raster 10 m), Europe, yearly* [Dataset]. European Environment Agency. <https://land.copernicus.eu/en/products/high-resolution-layer-forests-and-tree-cover/tree-cover-density-2023-raster-10-m-100-m-europe-yearly>

Corner, J. (2003). Landscape urbanism. In M. Mostafavi & C. Najle (Eds.), *Landscape urbanism: A manual for the machinic landscape* (pp. 58–63). Architectural Association.

Dal Borgo, A. G., Chiaffarelli, G., Capocéfalo, V., Schievano, A., Bocchi, S., & Vagge, I. (2023). Agroforestry as a Driver for the Provisioning of Peri-Urban Socio-Ecological Functions: A Trans-Disciplinary Approach. *Sustainability*, 15(14), 11020. <https://doi.org/10.3390/su151411020>

De Razza, S., Zanetti, C., De Marchi, M., & Pappalardo, S. E. (2024). Mapping urban heatwaves and islands: the reverse effect of Salento's "white cities". *Frontiers in Earth Science*, 12, 1375827. <https://doi.org/10.3389/feart.2024.1375827>

De Waegemaeker, J., Maarten, V. A., Kerselaers, E., & Rogge, E. (2021). The climate adaptation potential of the rural-urban fringe: exploring the climate impacts in the Brussels' territory through research by design. *4D Journal of Landscape Architecture and Garden Art*, (60), 2–17. <https://doi.org/10.36249/60.1>

Dee, C. (2004). *Form and Fabric in Landscape Architecture: A Visual Introduction*. London: Taylor & Francis. <https://doi.org/10.4324/9780203639078>

Demuzere, M., Kittner, J., Martilli, A., Mills, G., Moede, C., Stewart, I. D., Vliet, J., & Bechtel, B. (2022). A global map of local climate zones to support earth system modelling and urban-scale environmental science. *Earth System Science Data*, 14(8), 3835–3873. <https://doi.org/10.5194/essd-14-3835-2022>

Demuzere, M., Kittner, J., & Bechtel, B. (2021). LCZ Generator: A Web Application to Create Local Climate Zone Maps. *Frontiers in Environmental Science*, 9. <https://doi.org/10.3389/fenvs.2021.637455>

Demuzere, M., Bechtel, B., Middel, A., & Mills, G. (2019). Mapping Europe into local climate zones. *PLOS ONE*, 14(4), e0214474. <https://doi.org/10.1371/journal.pone.0214474>

Demuzere, M., Bechtel, B., & Mills, G. (2019). Global transferability of local climate zone models. *Urban Climate*, 27, 46-63. <https://doi.org/10.1016/j.uclim.2018.11.001>

Di Dato, C. (2024). Methodological Approach for Classifying Typical Recurrent Urban and Peri-Urban Configurations. In *Computational Science and Its Applications – ICCSA 2024 Workshops* (pp. 18-31). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-65238-7_2

Di Dato, C. (2024). Methodological Approach for Classifying Typical Recurrent Urban and Peri-Urban Configurations. In Gervasi, O., Murgante, B., Garau, C., Tanar, D., C. Rocha, A. M. A. & Faginas Lago, M. N. (Eds.), *Computational Science and Its Applications – ICCSA 2024 Workshops* (pp. 18-31). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-65238-7_2

Donadieu, P. (2013). *Campagne Urbane* (Nuova edizione italiana ed.). Roma: Donzelli.

Donateo, A., Palusci, O., Pappaccogli, G., Esposito, A., Martilli, A., Santiago, J. L., & Buccolieri, R. (2023). Analysis of urban heat island and human thermal comfort in a Mediterranean city: A case study of Lecce (Italy). *Sustainable Cities and Society*, 98, 104849. <https://doi.org/10.1016/j.scs.2023.104849>

Donateo, A., Palusci, O., Pappaccogli, G., Esposito, A., Martilli, A., Santiago, J. L., & Buccolieri, R. (2023). Analysis of urban heat island and human thermal comfort in a Mediterranean city: A case study of Lecce (Italy). *Sustainable Cities and Society*, 98, 104849. <https://doi.org/10.1016/j.scs.2023.104849>

Donateo, A., Palusci, O., Pappaccogli, G., Esposito, A., Martilli, A., Santiago, J. L., & Buccolieri, R. (2023). Analysis of urban heat island and human thermal comfort in a Mediterranean city: A case study of Lecce (Italy). *Sustainable Cities and Society*, 98, 104849. <https://doi.org/10.1016/j.scs.2023.104849>

Douglass, M. (1998). A Regional Network Strategy for Reciprocal Rural-Urban Linkages: An Agenda for Policy Research with Reference to Indonesia. *Third World Planning Review*, 20. <https://doi.org/10.3828/twpr.20.1.f2827602h503k5j6>

Esposito, A., Pappaccogli, G., Donateo, A., Salizzoni, P., Maffei, G., Semeraro, T., Santiago, J. L., & Buccolieri, R. (2024). Urban Morphology and Surface Urban Heat Island

Relationship During Heat Waves: A Study of Milan and Lecce (Italy). *Remote Sensing*, 16(23). <https://doi.org/10.3390/rs16234496>

Esposito, A., Grulois, M., Pappaccogli, G., Palusci, O., Donateo, A., Salizzoni, P., Santiago, J. L., Martilli, A., Maffei, G., & Buccolieri, R. (2023). On the Calculation of Urban Morphological Parameters Using GIS: An Application to Italian Cities. *Atmosphere*, 14(2), 329. <https://doi.org/10.3390/atmos14020329>

Esposito, A., Buccolieri, R., Santiago, J. L., & Pappaccogli, G. (2026). Intensification of SUHI During Extreme Heat Events: An Eight-Year Summer Analysis for Lecce (2018–2025). *Climate*, 14(1), 2. <https://doi.org/10.3390/cli14010002>

Esposito, A., Pappaccogli, G., Bozzeda, F., & Buccolieri, R. (2025). A multi-city statistical modelling of surface urban heat island: Application to Italian cities. *Urban Climate*, 64, 102717. <https://doi.org/10.1016/j.uclim.2025.102717>

Ferreira, C. S. S., Walsh, R. P. D., & Ferreira, A. J. D. (2018). Degradation in urban areas. *Current Opinion in Environmental Science & Health*, 5, 19–25. <https://doi.org/10.1016/j.coesh.2018.04.001>

Ferreira, F. L. e. S., Pereira, E. B., Gonçalves, A. R., Costa, R. S., & Bezerra, F. G. S. (2021). An explicitly spatial approach to identify heat vulnerable urban areas and landscape patterns. *Urban Climate*, 40, 101021. <https://doi.org/10.1016/j.uclim.2021.101021>

Franin, Kristijan; Ivanov, Kristina; Marčelić, Šime; Kuštera Franin, Gabrijela; Kos, Tomislav. Mediterranean dry stone walls as elements of ecological infrastructure // IOBC-WPRS Bulletin. Darmstadt: IOBC - WPRS, 2019. str. 75–78

Gallent, N. (2006). The Rural–Urban fringe: A new priority for planning policy?. *Planning Practice & Research*, 21(3), 383–393. <https://doi.org/10.1080/02697450601090872>

Gallent, N., & Shaw, D. (2007). Spatial planning, area action plans and the rural-urban fringe. *Journal of Environmental Planning and Management*, 50(5), 617–638. <https://doi.org/10.1080/09640560701475188>

Gallent, N., & Andersson, J. (2007). Representing England's rural-urban fringe. *Landscape Research - LANDSC RES*, 32, 1–21. <https://doi.org/10.1080/01426390601097495>

Gao, B. c. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment*, 58(3), 257–266. [https://doi.org/https://doi.org/10.1016/S0034-4257\(96\)00067-3](https://doi.org/https://doi.org/10.1016/S0034-4257(96)00067-3)

Gilabert, J., Deluca, A., Lauwaet, D., Ballester, J., Corbera, J., & Llasat, M. C. (2021). Assessing heat exposure to extreme temperatures in urban areas using the Local Climate

Zone classification. *Natural Hazards and Earth System Sciences*, 21(1), 375-391. <https://doi.org/10.5194/nhess-21-375-2021>

Gilabert, M. A., González-Piqueras, J., García-Haro, F. J., & Meliá, J. (2002). A generalized soil-adjusted vegetation index. *Remote Sensing of Environment*, 82(2), 303-310. [https://doi.org/10.1016/S0034-4257\(02\)00048-2](https://doi.org/10.1016/S0034-4257(02)00048-2)

Giorgi, F. (2006). Climate change hot-spots. *Geophysical Research Letters*, 33(8). <https://doi.org/10.1029/2006GL025734>

Hornero, A., Hernández-Clemente, R., North, P. R. J., Beck, P. S. A., Boscia, D., Navas-Cortes, J. A., & Zarco-Tejada, P. J. (2020). Monitoring the incidence of *Xylella fastidiosa* infection in olive orchards using ground-based evaluations, airborne imaging spectroscopy and Sentinel-2 time series through 3-D radiative transfer modelling. *Remote Sensing of Environment*, 236, 111480. <https://doi.org/10.1016/j.rse.2019.111480>

Huete, A. (1988). A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment*. *Remote Sensing of Environment*, 25, 295-309. [https://doi.org/10.1016/0034-4257\(88\)90106-X](https://doi.org/10.1016/0034-4257(88)90106-X)

Iaquina, D., & Drescher, A. (2000). Defining the peri-urban: Rural-urban linkages and institutional connections. *Land Reform, Land Settlement and Cooperatives*, , 8-27. https://www.researchgate.net/publication/287613842_Defining_the_peri-urban_Rural-urban_linkages_and_institutional_connections

Indovina, F. (1999). La città diffusa: cos'è e come si governa. https://www.researchgate.net/publication/277955686_La_citta_diffusa_cos'e_e_come_si_governa/citations

IPCC. (2022). *Climate change 2022: Impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, & B. Rama, Eds.). Cambridge University Press. <https://doi.org/10.1017/9781009325844>

Jaeger, J. A. (2000). Landscape division, splitting index, and effective mesh size: new measures of landscape fragmentation. *Landscape Ecology*, 15(2), 115-130. <https://doi.org/10.1023/A:1008129329289>

Kogan, F. N. (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research*, 15(11), 91-100. [https://doi.org/10.1016/0273-1177\(95\)00079-T](https://doi.org/10.1016/0273-1177(95)00079-T)

Leach, O., & Kenney, W. L. (2024). Aging and thermoregulation: Women are more vulnerable to heat at lower temperatures. *Journal of Applied Physiology*, 136(4), 823–832. <https://doi.org/10.1152/japplphysiol.00626.2023>

Liang, S. (2001). Narrowband to broadband conversions of land surface albedo I: Algorithms. *Remote Sensing of Environment*, 76(2), 213–238. [https://doi.org/10.1016/S0034-4257\(00\)00205-4](https://doi.org/10.1016/S0034-4257(00)00205-4)

Lionello, P., & Scarascia, L. (2020). The relation of climate extremes with global warming in the Mediterranean region and its north versus south contrast. *Regional Environmental Change*, 20(1), 31. <https://doi.org/10.1007/s10113-020-01610-z>

Lionello, P., & Scarascia, L. (2018). The relation between climate change in the Mediterranean region and global warming. *Regional Environmental Change*, 18(5), 1481–1493. <https://doi.org/10.1007/s10113-018-1290-1>

Liu, Y., Guaralda, M., Yigitcanlar, T., Limb, M., & Garcia-Hansen, V. (2025). Navigating urban climate design implementation challenges: insights from Brisbane's built environment experts. *Journal of Urban Design*, 30(3), 275–294. <https://doi.org/10.1080/13574809.2024.2376680>

Liu, Y. S., Yigitcanlar, T., Guaralda, M., Degirmenci, K., & Liu, A. (2024). Spatial Modelling of Urban Wind Characteristics: Review of Contributions to Sustainable Urban Development. *Buildings*, 14(3), 737. <https://doi.org/10.3390/buildings14030737>

Liu, L., & Zhang, Y. (2011). Urban Heat Island Analysis Using the Landsat TM Data and ASTER Data: A Case Study in Hong Kong. *Remote Sensing*, 3(7), 1535–1552. <https://doi.org/10.3390/rs3071535>

Lovello, E. M., Valente, D., & Petrosillo, I. (2025). Mitigating Land Degradation Through Sustainable Urban Landscapes Planning. *Sustainability*, 17(3), 967. <https://doi.org/10.3390/su17030967>

Maccabiani, E., Usmani, M., Nanni, R., & Napolitano, M. (2025). Investigating Social Vulnerability to Extreme Heat: Heat Islands and Climate Shelters in Urban Contexts: The Case of Bologna. *ISPRS International Journal of Geo-Information*, 14(1), 17. <https://doi.org/10.3390/ijgi14010017>

Magnaghi, A. (2015). Territorial forms and dimensions of a new urbanity demand - Full English version [Editorial]. *Scienze del Territorio*, (3), 356–358. <https://oajournals.fupress.net/index.php/sdt/article/download/8524/8522/8401>

- Mammadova, L., & Negri, S. (2024). Understanding the impacts of overexploitation on the Salento aquifer: A Comprehensive review through well data analysis. *Sustainable Futures*, 7, 100188. <https://doi.org/10.1016/j.sftr.2024.100188>
- Manyanya, T., Nethengwe, N. S., Verbist, B., & Somers, B. (2024). Optimizing Local Climate Zones through Clustering for Surface Urban Heat Island Analysis in Building Height-Scarce Cities: A Cape Town Case Study. *Climate*, 12(9), 142. <https://doi.org/10.3390/cli12090142>
- Martinelli, A., Kolokotsa, D. D., & Fiorito, F. (2020). Urban Heat Island in Mediterranean Coastal Cities: The Case of Bari (Italy). *Climate*, 8(6), 79. <https://doi.org/10.3390/cli8060079>
- Martinelli, A., Carlucci, F., & Fiorito, F. (2024). On the Role of the Building Envelope on the Urban Heat Island Mitigation and Building Energy Performance in Mediterranean Cities: A Case Study in Southern Italy. *Climate*, 12(8). <https://doi.org/10.3390/cli12080113>
- Martinelli, L., & Matzarakis, A. (2017). Influence of height/width proportions on the thermal comfort of courtyard typology for Italian climate zones. *Sustainable Cities and Society*, 29, 97-106. <https://doi.org/10.1016/j.scs.2016.12.004>
- McGarigal, K., & Marks, B. J. (1995). FRAGSTATS: *spatial pattern analysis program for quantifying landscape structure*. <https://doi.org/10.2737/PNW-GTR-351>
- Meeus, S. J., & Gulinck, H. (2008). Semi-Urban Areas in Landscape Research: A Review. *Living Rev. Landscape Res.*, 2. <https://doi.org/10.12942/lrlr-2008-3>
- Meeus, J. H. A., Wijermans, M. P., & Vroom, M. J. (1990). Agricultural landscapes in Europe and their transformation. *Landscape and Urban Planning*, 18(3), 289-352. [https://doi.org/10.1016/0169-2046\(90\)90016-U](https://doi.org/10.1016/0169-2046(90)90016-U)
- Mortoja, M. G., & Yigitcanlar, T. (2022). Why is determining peri-urban area boundaries critical for sustainable urban development?. *Journal of Environmental Planning and Management*, 66(1), 67-96. <https://doi.org/10.1080/09640568.2021.1978405>
- Naim, M. N. H., & Kafy, A. A. (2021). Assessment of urban thermal field variance index and defining the relationship between land cover and surface temperature in Chattogram city: A remote sensing and statistical approach. *Environmental Challenges*, 4, 100107. <https://doi.org/10.1016/j.envc.2021.100107>
- Nardino, M., Cremonini, L., Crisci, A., Georgiadis, T., Guerri, G., Morabito, M., & Fiorillo, E. (2022). Mapping daytime thermal patterns of Bologna municipality (Italy) during a heatwave: A new methodology for cities adaptation to global climate change. *Urban Climate*, 46, 101317. <https://doi.org/10.1016/j.uclim.2022.101317>

- Nguyen, C. T., Chidthaisong, A., Kieu Diem, P., & Huo, L. Z. (2021). A Modified Bare Soil Index to Identify Bare Land Features during Agricultural Fallow-Period in Southeast Asia Using Landsat 8. *Land*, 10(3), 231. <https://doi.org/10.3390/land10030231>
- Nickayin, S. S., Salvati, L., Coluzzi, R., Lanfredi, M., Halbac-Cotoara-Zamfir, R., Salvia, R., Quaranta, G., Alhuseen, A., & Gaburova, L. (2021). What Happens in the City When Long-Term Urban Expansion and (Un)Sustainable Fringe Development Occur: The Case Study of Rome. *ISPRS International Journal of Geo-Information*, 10(4). <https://doi.org/10.3390/ijgi10040231>
- Orlandi, F., Marrapodi, S., Proietti, C., Ruga, L., & Fornaciari, M. (2022). Ecosystem functions of fruit woody species in an urban environment. *Environmental Monitoring and Assessment*, 195(1), 118. <https://doi.org/10.1007/s10661-022-10717-1>
- Oke, T. R. (1982). The energetic basis of the urban heat island. *Quarterly Journal of the Royal Meteorological Society*, 108(455), 1-24. <https://doi.org/10.1002/qj.49710845502>
- Oke, T. R. (1987). *Boundary Layer Climates* (2 ed.). London: Routledge. <https://doi.org/10.4324/9780203407219>
- Padasas, I. (2019). *Designing resilient rural-urban landscapes: Policy and planning for peri-urban green infrastructure*. Routledge.
- Pappaccogli, G., Giangrande, F., Esposito, A., Donato, A., Lionello, P., & Buccolieri, R. (2024). Dynamics of urban heat island intensity in Lecce, Italy: seasonal, diurnal and heat wave influence. *Bulletin of Atmospheric Science and Technology*, 5(1), 8. <https://doi.org/10.1007/s42865-024-00072-z>
- Pappaccogli, G., Esposito, A., & Buccolieri, R. (2025). Summer Diurnal LST Variability Across Local Climate Zones Using ECOSTRESS Data in Lecce and Milan. *Atmosphere*, 16(4), 377. <https://doi.org/10.3390/atmos16040377>
- Parida, B. R., Oinam, B., Patel, N. R., Sharma, N., & Kandpal, R. (2008). Land surface temperature variation in relation to vegetation types using MODIS satellite data in Gujarat state of India. *International Journal of Remote Sensing*, 29(14), 4219-4235. <https://doi.org/10.1080/01431160701871096>
- Parise, M. (2011). Surface and subsurface karst geomorphology in the Murge (Apulia, Southern Italy). *Acta Carsologica*, 40(1). <https://doi.org/10.3986/ac.v40i1.30>
- Parise, M. (2003). Flood history in the karst environment of Castellana-Grotte (Apulia, southern Italy). *Natural Hazards and Earth System Sciences*, 3(6), 593-604. <https://doi.org/10.5194/nhess-3-593-2003>

- Pijpers-van Esch, M. (2015). *Designing the Urban Microclimate: A framework for a design-decision support tool for the dissemination of knowledge on the urban microclimate to the urban design process*. (2015). *A+BE | Architecture and the Built Environment*, 5(6), 1-310. <https://aplusbe.eu/index.php/p/article/view/413>
- Pisano, L., Zumpano, V., Pepe, M., Liso, I. S., & Parise, M. (2022). Assessing Karst Landscape Degradation: A Case Study in Southern Italy. *Land*, 11(10), 1842. <https://doi.org/10.3390/land11101842>
- Pont, M. B., & Haupt, P. (2023). *Spacematrix: Space, Density and Urban Form - revised edition*. TU Delft OPEN Books. <https://doi.org/10.59490/mg.38>
- Qiu, G. y., Li, H. y., Zhang, Q. t., Chen, W., Liang, X. j., & Li, X. z. (2013). Effects of Evapotranspiration on Mitigation of Urban Temperature by Vegetation and Urban Agriculture. *Journal of Integrative Agriculture*, 12(8), 1307-1315. [https://doi.org/10.1016/S2095-3119\(13\)60543-2](https://doi.org/10.1016/S2095-3119(13)60543-2)
- Qiu, G. Y., Zou, Z., Li, X., Li, H., Guo, Q., Yan, C., & Tan, S. (2017). Experimental studies on the effects of green space and evapotranspiration on urban heat island in a subtropical megacity in China. *Habitat International*, 68, 30-42. <https://doi.org/10.1016/j.habitatint.2017.07.009>
- Rees, W. E. (1992). Ecological footprints and appropriated carrying capacity: what urban economics leaves out. *Environment & Urbanization*, 4(2), 121-130. <https://doi.org/10.1177/095624789200400212>
- Ren, H., Zhou, G., & Zhang, F. (2018). Using negative soil adjustment factor in soil-adjusted vegetation index (SAVI) for aboveground living biomass estimation in arid grasslands. *Remote Sensing of Environment*, 209, 439-445. <https://doi.org/10.1016/j.rse.2018.02.068>
- Ren, C., Cai, M., Li, X., Zhang, L., Wang, R., Xu, Y., & Ng, E. (2019). Assessment of Local Climate Zone Classification Maps of Cities in China and Feasible Refinements. *Scientific Reports*, 9(1), 18848. <https://doi.org/10.1038/s41598-019-55444-9>
- Rikimaru, A., Roy, P. S., & Miyatake, S. (2002). Tropical forest cover density mapping. *Tropical Ecology*, 43(1), 39-47.
- Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the great plains with ERTS. *SciSpace - Paper*, 1, 309-317. <https://scispace.com/papers/monitoring-vegetation-systems-in-the-great-plains-with-erts-1a87ioiz6m>

- Sandholt, I., Rasmussen, K., & Andersen, J. (2002). A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. *Remote Sensing of Environment*, 79(2), 213-224. [https://doi.org/10.1016/S0034-4257\(01\)00274-7](https://doi.org/10.1016/S0034-4257(01)00274-7)
- Sordi, J. (2014). Beyond urbanism. *ListLab*.
- Stewart, I. D., & Oke, T. R. (2012). Local Climate Zones for Urban Temperature Studies. *Bulletin of the American Meteorological Society*, 93(12), 1879-1900. <https://doi.org/10.1175/BAMS-D-11-00019.1>
- Tacoli, C. (1998). Rural-urban interactions: a guide to the literature. *Environment & Urbanization*, 10(1), 147-166. <https://doi.org/10.1177/095624789801000105>
- Tarantino, A., Frabboni, L., & Disciglio, G. (2021). Water-Yield Relationship and Vegetative Growth of Wonderful Young Pomegranate Trees under Deficit Irrigation Conditions in Southeastern Italy. *Horticulturae*, 7(4), 79. <https://doi.org/10.3390/horticulturae7040079>
- Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment*, 8(2), 127-150. [https://doi.org/10.1016/0034-4257\(79\)90013-0](https://doi.org/10.1016/0034-4257(79)90013-0)
- USGS / EROS Center. (2020). *Landsat Collection 2 Level-2 Science Products* [Dataset]. United States Geological Survey. <https://doi.org/10.5066/P9OGBGM6>
- Valdivieso-Ros, C., Alonso-Sarria, F., & Gomariz-Castillo, F. (2023). Effect of the Synergetic Use of Sentinel-1, Sentinel-2, LiDAR and Derived Data in Land Cover Classification of a Semiarid Mediterranean Area Using Machine Learning Algorithms. *Remote Sensing*, 15(2), 312. <https://doi.org/10.3390/rs15020312>
- Valente, D., Lovello, E. M., Chirizzi, R., & Petrosillo, I. (2024). Multiscale Effects of *Xylella fastidiosa* on Landscape Services. *Land*, 13(12), 1-18. <https://ideas.repec.org//a/gam/jlands/v13y2024i12p2087-d1536228.html>
- Valente, D., Marinelli, M. V., Lovello, E. M., Giannuzzi, C. G., & Petrosillo, I. (2022). Fostering the Resiliency of Urban Landscape through the Sustainable Spatial Planning of Green Spaces. *Land*, 11(3), 367. <https://doi.org/10.3390/land11030367>
- Van Steen, Y., Ntarladima, A. M., Grobbee, R., Karssenbergh, D., & Vaartjes, I. (2019). Sex differences in mortality after heat waves: Are elderly women at higher risk? *International Archives of Occupational and Environmental Health*, 92(1), 37-48. <https://doi.org/10.1007/s00420-018-1360-1>

- Vigano, P., Cavalieri, C., & Corte, M. (2018). *The Horizontal Metropolis Between Urbanism and Urbanization*. . <https://doi.org/10.1007/978-3-319-75975-3>
- Viganò, P., Cavalieri, C., & Corte, M. M. (2018). *Recycling city: Lifecycles, embodied energy, multiple metabolisms*. List Lab.
- Vizzari, M. (2011). Spatio-Temporal Analysis Using Urban-Rural Gradient Modelling and Landscape Metrics. In Murgante, B., Gervasi, O., Iglesias, A., Tanar, D. & Aduhan, B. O. (Eds.), *Computational Science and Its Applications - ICCSA 2011* (pp. 103-118). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-21928-3_8
- Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote Sensing of Environment*, 86(3), 370-384. [https://doi.org/10.1016/S0034-4257\(03\)00079-8](https://doi.org/10.1016/S0034-4257(03)00079-8)
- Waldheim, C. (2016). *Landscape as Urbanism: A General Theory*. Princeton University Press. <https://doi.org/10.2307/j.ctvczzn2>
- Wandl, A., & Magoni, M. (2017). Sustainable Planning of Peri-Urban Areas: Introduction to the Special Issue. *Planning Practice & Research*, 32(1), 1-3. <https://doi.org/10.1080/02697459.2017.1264191>
- Wilson, E. H., & Sader, S. A. (2002). Detection of forest harvest type using multiple dates of Landsat TM imagery. *Remote Sensing of Environment*, 80(3), 385-396. [https://doi.org/10.1016/S0034-4257\(01\)00318-2](https://doi.org/10.1016/S0034-4257(01)00318-2)
- Wu, K.-L., & Shan, L. (2024). Make Way for the Wind—Promoting Urban Wind Corridor Planning by Integrating RS, GIS, and CFD in Urban Planning and Design to Mitigate the Heat Island Effect. *Atmosphere*, 15(3), 257. <https://doi.org/10.3390/atmos15030257>
- Yuan, G., Zhang, Y., Li, E., & Liu, Y. (2023). Effects of Different Land Use Types on Soil Surface Temperature in the Heihe River Basin. *Sustainability*, 15(4), 3859. <https://doi.org/10.3390/su15043859>
- Yuan, F., & Bauer, M. E. (2007). Comparison of impervious surface area and normalized difference vegetation index as indicators of surface urban heat island effects in Landsat imagery. *Remote Sensing of Environment*, 106(3), 375-386. <https://doi.org/10.1016/j.rse.2006.09.003>

Appendices

Appendices

APPENDIX A

Phase 1–3 Cross-Validation Framework

A.1 Phase 1–3 Baseline Extraction: Complete Operations Inventory

Section 4.4 of the main thesis presents the Phase 1–3 framework in a four-row compact summary table (Table 4.1) and signals the existence of full documentation here. The Phase 1–3 pipeline is the analytical foundation of the RUTZ ecology classification: it fuses Urban Atlas 2021 vector polygons (Phase 1), Copernicus Crop Type 2023 raster masks (Phase 2), and a multi-source abandonment confidence raster (Phase 3) into a cross-validated composite for each of the three ecologies, with explicit treatment of the ambiguous UA 32000 herbaceous class. Table A.1 below documents every operation in this thirteen-step pipeline, with source datasets, ArcGIS Pro procedures, output feature classes, and the role each output plays in the downstream RUTZ analysis. All outputs are stored in the Lecce Prime geodatabase under the EPSG:32634 projection.

Table A.1 Phase 1–3 Complete Operations Inventory

Phase	Operation	Procedure summary	Key output(s)	Role in RUTZ pipeline
Phase 1.1	Baseline A - Rural Agricultural	Select UA code 21000 (Arable Land) + 23000 (Pastures) from CLMS_UA_2021 → Export → Clip to Grid_Limit	BL_A1_ArableLand_2021_Clipped, BL_A2_Pastures_2021_Clipped, BL_A_Combined_2021_Clipped	SUHI_A thermal baseline (3,425.93 ha combined)
Phase 1.2	Baseline B - Orchard (Il Giardino)	Select UA code 22000 (Permanent Crops) → Export → Clip → Cross-validate majority class via Zonal Statistics against CROP_Types_2023: polygons where MAJORITY = Olives/Fruits/Nuts/Grapes → BL_B_Validated; polygons where MAJORITY = NoCropland → BL_B_AbandonedOrchard_Flag	BL_B_Validated_2021 (134.66 ha confirmed olive) BL_B_AbandonedOrchard_Flag (Phase 3 Frangia input)	SUHI_B thermal baseline; primary G1 ecology layer
Phase 1.3	Baseline MX - Mixed Cultivation	Select UA code 24000 (Complex & Mixed Cultivation)	BL_MX_ComplexCultivation_2021_Clipped	Transitional / mixed ecology context
Phase 1.4	Reference Forest - Broadleaved	Select UA code 31000 (Forests) → Cross-validate with Forest Type 2023 raster: MAJORITY = 2 (Broadleaved) → exported separately	REF_Forest_Broadleaved_2021 (104.88 ha)	Maximum cooling ceiling scalar (SUHI_D)
Phase 1.5	Baseline C - Lithic Core	Select UA codes 11100 (Continuous Urban, ISF >80%), 11210 (Discontinuous Dense, 50–80%), 11220 (Medium Density, 30–50%)	BL_C1/C2/C3 + BL_C_AllUrban_2021_Clipped (140.74 ha C1)	SUHI_C thermal baseline; La Pietra urban body

Phase	Operation	Procedure summary	Key output(s)	Role in RUTZ pipeline
Phase 1.6	La Frangia UA source classes	Select UA codes 13400 (Land No Use), 13300 (Construction Sites), 13100 (Extraction/Quarry) → Merge with Frangia_Type field	FRAN_UA_Combined_2021	Structural Frangia (visible to UA: ~129.94 ha)
Phase 1.7	Il Giardino green space	Select UA codes 14110/14120/14130 (Urban Green) + 32000 (Herbaceous Veg) → Merge with Giardino_Type field	GRN_Giardino_AllClasses_2021 (provisional, 315 polygons)	Later refined to 182 polygons in Phase 3.6
Phase 2.1–2.4	Crop Type raster masks	Reclassify CROP_Types_2023 (10m) into 8 thematic binary masks. Tool: ArcGIS Pro Reclassify (Spatial Analyst). Snap raster enforces pixel-grid alignment.	CROP_Olives (588.28 ha), CROP_PermanentAll (631.64 ha), CROP_AnnualAll (793.55 ha), CROP_NoCropland (6,992.63 ha = 81.07%), CROP_Unclassified (3100/3200 coded), CROP_SuperClasses (7-class)	Cross-validation evidence for Baseline B; abandonment input for Phase 3
Phase 3.1	Ploughing Indicator reclassification	Reclassify HRLVLCC Ploughing Indicator 2023 (time-since-ploughing raster, NOT frequency): Values 3–5 (long fallow) → Class 1 (LongFallow); 0–2 → Class 2 (Active); 100/253 → Class 3 (NoInfo, no evidence). Value 253 covers 93.8% of cells; assigned zero abandonment weight.	PLI_Reclass_2023 LongFallow: 1,908 cells (19.08 ha) Active: 51,901 cells NoInfo: 808,691 cells	Term B of the abandonment confidence sum (Eq. 3)
Phase 3.2	Abandonment Confidence Raster	Raster Calculator sum of three independent binary evidence streams: (A) CROP_NoCropland mask + (B) PLI_LongFallow class + (C) CROP_Unclassified value 3200 (Undecided Perennial). IsNull guard on Term C prevents NoData propagation.	FRAN_AbandonmentConfidence_2023 0 (no evidence): 161,421 cells 1 (weak): 699,723 cells 2 (high confidence): 1,356 cells 3 (maximum): 0 cells (PLI coverage gap prevents triple coincidence)	Core abandonment evidence raster
Phase 3.3–3.4	High-confidence mask + spatial constraint	Threshold ≥ 2 via Con tool → FRAN_HighConfidence_Abandoned_2023. Extract by Mask against merged agricultural polygons (BL_A + BL_B + BL_MX + GRN) → removes urban/forest NoCropland pixels.	FRAN_HighConf_Agricultural_2023: 1,268 cells (12.68 ha)	88 non-agricultural cells removed (0.88 ha)
Phase 3.5	UA 32000 herbaceous bifurcation	Zonal Statistics MAJORITY of 4 rasters (Herbaceous Cover 2023, Grassland 2023, PLI_Reclass, NoCropland) against 232 UA 32000 polygons (806.82 ha) → Python conditional populates Bifurcation_Class field.	G3_Functional: 99 polygons, 405.47 ha (50.3%) Ambiguous: 116 polygons, 315.58 ha (39.1%) F4_DryHerbaceous: 17 polygons, 85.77 ha (10.6%)	Functional subset retained in Il Giardino; dry subset reassigned to La Frangia as F4
Phase 3.6	Refined Il Giardino composite	Merge: BL_B_Validated + REF_Forest_Broadleaved + GRN_HerbaceousFunctional + 3× GRN_UrbanGreen sub-classes → 6 Giardino_Type values, zero nulls.	GRN_Giardino_Functional_2021: 182 polygons, 705.47 ha	Replaces provisional 315-polygon layer for all downstream analysis
Phase 3.7	La Frangia composite	Merge 6 source layers across F1–F4 typology.	FRAN_Composite_2021: 247 polygons, 780.64 ha F1 72.37% • F2 9.14% • F3 7.50% • F4 10.99%	83.4% invisible to UA 2021 uni-source classification

Note. Phase 1–3 baseline extraction and cross-validation framework. The pipeline fuses Urban Atlas 2021 vector polygons (Phase 1), Copernicus Crop Type 2023 raster masks (Phase 2), and a multi-source abandonment confidence raster (Phase 3) to produce the definitive ecology vector layers that feed all downstream RUTZ analysis. All outputs stored in Lecce Prime geodatabase; CRS EPSG:32634. The compact summary version of this table appears in the main text as Table 4.1 (§4.4).

APPENDIX B

Supplementary Thermal & Spectral Documentation

Overview. This appendix consolidates the multi-season thermal and spectral tables and the sensor manifest supporting the empirical chapters. It is organized in six sections (B.1–B.6). B.1 reports per-ecology means for every spectral and thermal index across the full four-year, three-season Landsat record. B.2 reports the same metrics organized by Peri-Urban Class, with the operational band (Classes 4+5) highlighted throughout, the analytical scaffold for Chapter 9's calibration and Chapter 10's intervention strategy. B.3 documents the SUHI variants. B.4 documents the albedo distribution supporting the §7.7 mechanism argument. B.5 documents the independent spectral witnesses (NDBI, BSI). B.6 provides the complete Landsat sensor manifest and data provenance record.

B.1 Multi-Season Summary Tables: By Dominant Ecology

This section reports cell-aggregated means of every spectral and thermal index across the twelve Landsat scenes, organized by Dominant Ecology (Stone, Shadow, Fire, Transitional). The tables read in the same direction as the Chapter 7 narrative: each row is a year–season scene; each column is one ecology. The row maximum across the four ecologies is highlighted in light terracotta, making the seasonal LST inversion (Spring: Fire highest → Summer: Stone highest) legible at a glance.

Ecology cell counts (7-metric Provisional Dominant Ecology classification): Stone n=4,306 (49.9%); Transitional n=3,635 (42.1%); Shadow n=465 (5.4%); Fire n=219 (2.5%). Source: FISHNET Master Profile field 'Dominant Ecology'.

Independent witnesses vs. rescaling: LST, NDMI, BSI, NDVI, SAVI, NDBI, Albedo are derived from reflectance and thermal bands and are mutually independent witnesses. SMI (Table B.1.6) and TVDI (Table B.1.7) are within-scene linear rescaling of LST ($r = -1.00$ by construction) and are documented for reproducibility rather than as independent evidence.

Table B.1.1 Mean Land Surface Temperature (°C)

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	30.55°	30.78°	32.12°	31.35°
	Summer	L8	47.98°	46.48°	46.13°	46.33°
	Winter	L8	13.41°	12.57°	11.93°	12.20°
2018	Spring	L8	34.49°	34.55°	35.53°	34.96°
	Summer	L8	44.41°	43.49°	43.91°	43.69°
	Winter	L8	11.82°	11.56°	11.12°	11.26°
2021	Spring	L8	33.06°	33.87°	35.52°	34.58°
	Summer	L8	47.85°	46.09°	45.70°	45.87°
	Winter	L8	21.12°	20.70°	20.77°	20.68°
2025	Spring	L9	28.48°	29.32°	31.33°	30.22°
	Summer	L8	46.94°	45.48°	45.21°	45.36°
	Winter	L9	15.95°	15.33°	15.01°	15.17°

Note. The seasonal inversion is legible row by row: in every spring scene, Fire registers the highest mean LST; in every Summer scene, Stone registers the highest. The pattern holds across all four years. Source: FISHNET Thermal TimeSeries field MEAN_LST_{year}{season}_{sensor}; Landsat 8/9 Collection-2 Level-2; EPSG:32634.

Table B.1.2 Mean NDMI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	0.179	0.126	-0.009	0.054
	Summer	L8	-0.083	-0.020	-0.050	-0.042
	Winter	L8	0.115	0.143	0.029	0.076
2018	Spring	L8	0.167	0.110	-0.003	0.052

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
	Summer	L8	-0.040	0.013	-0.034	-0.018
	Winter	L8	0.150	0.159	0.028	0.081
2021	Spring	L8	0.191	0.125	-0.003	0.062
	Summer	L8	-0.109	-0.037	-0.055	-0.052
	Winter	L8	0.164	0.149	0.010	0.077
2025	Spring	L9	0.239	0.153	0.007	0.082
	Summer	L8	-0.091	-0.025	-0.052	-0.047
	Winter	L9	0.201	0.234	0.072	0.141

Note. Stone shows the highest NDMI in every Spring scene; every summer scene records canopy moisture collapse across all four ecologies. The §7.3 dry-summer decoupling reads directly from the column-wise spring-to-summer change. Source: FISHNET Thermal TimeSeries.

Table B.1.3 Mean BSI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	-0.102	-0.048	0.075	0.016
	Summer	L8	0.136	0.087	0.114	0.106
	Winter	L8	-0.043	-0.060	0.052	0.004
2018	Spring	L8	-0.081	-0.025	0.078	0.026
	Summer	L8	0.095	0.054	0.100	0.083
	Winter	L8	-0.080	-0.080	0.051	-0.004
2021	Spring	L8	-0.105	-0.040	0.075	0.015
	Summer	L8	0.164	0.104	0.119	0.115
	Winter	L8	-0.089	-0.066	0.065	0.001
2025	Spring	L9	-0.154	-0.068	0.067	-0.004
	Summer	L8	0.149	0.094	0.118	0.112
	Winter	L9	-0.126	-0.148	0.017	-0.056

Note. Fire consistently records highest summer BSI, reflecting its peri-urban built-and-exposed configuration at hectare scale. Source: FISHNET Thermal TimeSeries.

Table B.1.4 Mean NDVI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	0.619	0.527	0.320	0.421
	Summer	L8	0.339	0.364	0.271	0.313
	Winter	L8	0.555	0.538	0.354	0.440
2018	Spring	L8	0.571	0.484	0.303	0.392
	Summer	L8	0.416	0.419	0.290	0.348
	Winter	L8	0.601	0.562	0.352	0.447
2021	Spring	L8	0.595	0.504	0.312	0.408
	Summer	L8	0.310	0.352	0.262	0.302
	Winter	L8	0.597	0.535	0.329	0.431

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2025	Spring	L9	0.642	0.529	0.323	0.429
	Summer	L8	0.315	0.356	0.264	0.302
	Winter	L9	0.621	0.614	0.399	0.495

Note. Stone returns highest spring NDVI in all four years (open karst flushed with herbaceous growth on winter moisture charge) and the steepest spring-to-summer decline. Source: FISHNET Thermal TimeSeries.

Table B.1.5 Mean SAVI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	0.404	0.337	0.205	0.268
	Summer	L8	0.224	0.241	0.183	0.208
	Winter	L8	0.335	0.307	0.194	0.246
2018	Spring	L8	0.375	0.316	0.203	0.257
	Summer	L8	0.266	0.273	0.198	0.229
	Winter	L8	0.348	0.315	0.192	0.246
2021	Spring	L8	0.386	0.328	0.207	0.266
	Summer	L8	0.201	0.230	0.178	0.200
	Winter	L8	0.372	0.326	0.197	0.259
2025	Spring	L9	0.429	0.348	0.212	0.281
	Summer	L8	0.210	0.237	0.180	0.202
	Winter	L9	0.367	0.346	0.210	0.271

Note. SAVI ($L = 0.5$) is NDVI corrected for soil-brightness background; the relative ecology ordering follows NDVI but with absolute magnitudes compressed. Source: FISHNET Thermal TimeSeries.

Table B.1.6 Mean SMI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	0.619	0.605	0.523	0.571
	Summer	L8	0.521	0.602	0.622	0.611
	Winter	L8	0.476	0.554	0.613	0.588
2018	Spring	L8	0.591	0.588	0.534	0.566
	Summer	L8	0.453	0.511	0.485	0.498
	Winter	L8	0.541	0.569	0.616	0.601
2021	Spring	L8	0.652	0.601	0.498	0.557
	Summer	L8	0.285	0.349	0.363	0.356
	Winter	L8	0.541	0.583	0.576	0.585
2025	Spring	L9	0.628	0.580	0.467	0.530
	Summer	L8	0.525	0.605	0.620	0.612
	Winter	L9	0.347	0.393	0.417	0.405

Note. SMI is a within-scene linear rescaling of LST ($r = -1.00$ by construction). Documented here for reproducibility; the inversion seen is the same inversion present in Table B.1.1. Source: FISHNET Thermal TimeSeries.

Table B.1.7 Mean TVDI

Year	Season	Sensor	Stone n=4,306	Shadow n=465	Fire n=219	Transitional n=3,635
2015	Spring	L8	0.644	0.622	0.487	0.565
	Summer	L8	0.370	0.481	0.507	0.492
	Winter	L8	0.388	0.504	0.595	0.557
2018	Spring	L8	0.575	0.569	0.484	0.534
	Summer	L8	0.347	0.421	0.387	0.405
	Winter	L8	0.272	0.329	0.422	0.393
2021	Spring	L8	0.652	0.574	0.415	0.506
	Summer	L8	0.220	0.295	0.312	0.305
	Winter	L8	0.605	0.656	0.648	0.659
2025	Spring	L9	0.687	0.625	0.474	0.558
	Summer	L8	0.476	0.573	0.591	0.582
	Winter	L9	0.435	0.553	0.615	0.584

Note. TVDI is, like SMI, a within-scene rescaling of LST. Documented for completeness. Source: FISHNET Thermal TimeSeries.

B.2 Multi-Season Summary Tables: By Peri-Urban Class

This section reports cell-aggregated means across the same twelve Landsat scenes, but organized by Peri-Urban Class (Rural Matrix → Margin Approach → Transition Mosaic → Active Margin → Critical Fringe). The operational peri-urban band (Active Margin + Critical Fringe, marked with ★) is the analytical domain of Chapter 9's RUTZ Index calibration and Chapter 10's Point–Line–Surface intervention strategy. Both operational classes appear with a light shading throughout this section so the reader can follow the gradient toward the cells of intervention without losing the contrast against the non-operational classes.

Peri-Urban Class cell counts: Rural Matrix n=1,535 (17.8%); Margin Approach n=2,107 (24.4%); Transition Mosaic n=2,514 (29.1%); Active Margin n=1,763 (20.4%); Critical Fringe n=706 (8.2%). Operational peri-urban band (Classes 4 + 5): 2,469 cells / 28.6% of grid. Source: FISHNET Master Profile field 'Peri-Urban Class' (Jenks natural-break classification of composite peri-urban score, §6.6).

Reading guidance. Summer 2025 LST (Table B.2.1, row 11) reads as the gradient from Rural Matrix (46.92 °C) to Critical Fringe (45.56 °C), a 1.4°C cooling as the cells becomes more peri-urban — the reverse-UHI signature at the gradient scale. The same row in Table B.2.2 (NDMI) shows the parallel trajectory: the operational classes carry less negative summer NDMI than the Rural Matrix, signaling that the moisture reserve sustaining whatever residual evapotranspiration remains in the territory is concentrated precisely in the cells where intervention can still act.

Table B.2.1 Mean Land Surface Temperature (°C) by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	30.58°	30.79°	31.14°	31.10°	31.05°
	Summer	L8	48.13°	47.57°	46.84°	46.53°	46.46°
	Winter	L8	13.42°	13.10°	12.52°	12.50°	12.53°
2018	Spring	L8	34.40°	34.65°	34.92°	34.78°	34.76°
	Summer	L8	44.37°	44.26°	43.98°	43.73°	43.73°
	Winter	L8	11.80°	11.64°	11.42°	11.44°	11.51°
2021	Spring	L8	32.91°	33.54°	34.19°	34.20°	34.20°
	Summer	L8	47.97°	47.26°	46.51°	46.21°	46.16°
	Winter	L8	21.17°	21.03°	20.79°	20.74°	20.75°
2025	Spring	L9	28.25°	29.13°	29.71°	29.78°	29.78°
	Summer	L8	46.92°	46.50°	45.91°	45.64°	45.56°
	Winter	L9	15.94°	15.73°	15.42°	15.34°	15.35°

Note. Summer LST declines monotonically across the gradient from Rural Matrix to Critical Fringe in every year of the record, confirming the §7.4 reverse-UHI argument at the operational scale of Chapter 9's RUTZ Index. 4-year summer mean: Rural Matrix 46.85 °C → Margin Approach 46.40 °C → Transition Mosaic 45.81 °C → Active Margin 45.53 °C → Critical Fringe 45.48 °C. ★ marks operational classes.

Table B.2.2 Mean NDMI by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	0.183	0.140	0.089	0.091	0.091
	Summer	L8	-0.088	-0.079	-0.056	-0.037	-0.033
	Winter	L8	0.099	0.091	0.093	0.107	0.110
2018	Spring	L8	0.177	0.132	0.082	0.083	0.083
	Summer	L8	-0.040	-0.039	-0.027	-0.011	-0.008
	Winter	L8	0.141	0.115	0.107	0.117	0.122
2021	Spring	L8	0.202	0.150	0.097	0.096	0.093
	Summer	L8	-0.110	-0.094	-0.074	-0.055	-0.052
	Winter	L8	0.158	0.130	0.106	0.111	0.111
2025	Spring	L9	0.247	0.189	0.128	0.124	0.122
	Summer	L8	-0.091	-0.081	-0.064	-0.046	-0.043
	Winter	L9	0.184	0.176	0.159	0.180	0.183

Note. NDMI rises monotonically across the gradient in summer (less negative in operational classes). Critical Fringe NDMI is the highest of any summer class in 2025 (-0.043 vs Rural Matrix -0.091), confirming that the buffer mechanism is still partially functional at the most peri-urban cells — the precise condition that justifies intervention.

Table B.2.3 Mean BSI by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	-0.106	-0.066	-0.017	-0.017	-0.017
	Summer	L8	0.141	0.133	0.117	0.101	0.097
	Winter	L8	-0.028	-0.019	-0.015	-0.026	-0.029
2018	Spring	L8	-0.090	-0.048	-0.002	-0.001	-0.002
	Summer	L8	0.096	0.096	0.089	0.076	0.072
	Winter	L8	-0.071	-0.044	-0.032	-0.039	-0.044
2021	Spring	L8	-0.116	-0.067	-0.017	-0.015	-0.013
	Summer	L8	0.166	0.150	0.135	0.118	0.115
	Winter	L8	-0.083	-0.056	-0.029	-0.032	-0.031
2025	Spring	L9	-0.162	-0.106	-0.047	-0.041	-0.040
	Summer	L8	0.150	0.140	0.127	0.111	0.108
	Winter	L9	-0.110	-0.099	-0.078	-0.095	-0.098

Note. BSI declines monotonically across the gradient in summer, mirroring the NDMI rise. Source: FISHNET Thermal TimeSeries.

Table B.2.4 Mean NDVI by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	0.618	0.556	0.479	0.479	0.482
	Summer	L8	0.330	0.322	0.321	0.337	0.343
	Winter	L8	0.536	0.509	0.479	0.492	0.497
2018	Spring	L8	0.575	0.513	0.444	0.443	0.445
	Summer	L8	0.412	0.387	0.367	0.380	0.384
	Winter	L8	0.590	0.541	0.499	0.506	0.512
2021	Spring	L8	0.602	0.534	0.462	0.461	0.457
	Summer	L8	0.305	0.302	0.301	0.321	0.323
	Winter	L8	0.589	0.538	0.484	0.488	0.486
2025	Spring	L9	0.648	0.573	0.491	0.489	0.486
	Summer	L8	0.312	0.307	0.301	0.322	0.325
	Winter	L9	0.602	0.576	0.533	0.554	0.555

Note. NDVI shows little class-wise variation across the gradient in summer because the Mediterranean dry-summer senescence (§7.3) decouples greenness from cooling. Source: FISHNET Thermal TimeSeries.

Table B.2.5 Mean SAVI by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	0.406	0.362	0.307	0.306	0.309
	Summer	L8	0.219	0.212	0.212	0.223	0.228
	Winter	L8	0.325	0.303	0.275	0.279	0.283
2018	Spring	L8	0.380	0.337	0.290	0.290	0.293
	Summer	L8	0.265	0.249	0.238	0.248	0.252
	Winter	L8	0.341	0.308	0.281	0.283	0.287
2021	Spring	L8	0.391	0.348	0.300	0.300	0.300
	Summer	L8	0.199	0.198	0.197	0.210	0.213
	Winter	L8	0.367	0.333	0.296	0.297	0.297
2025	Spring	L9	0.434	0.381	0.324	0.322	0.321
	Summer	L8	0.209	0.204	0.201	0.215	0.218
	Winter	L9	0.354	0.334	0.302	0.310	0.312

Note. SAVI distribution by class confirms the NDVI senescence pattern with soil-background correction applied. Source: FISHNET Thermal TimeSeries.

Table B.2.6 Mean SMI by Peri-Urban Class

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	0.617	0.605	0.583	0.586	0.588
	Summer	L8	0.513	0.543	0.583	0.599	0.603
	Winter	L8	0.476	0.505	0.559	0.560	0.557
2018	Spring	L8	0.597	0.583	0.568	0.576	0.577

Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
	Summer	L8	0.456	0.463	0.480	0.496	0.496
	Winter	L8	0.543	0.560	0.584	0.582	0.575
2021	Spring	L8	0.662	0.622	0.582	0.581	0.581
	Summer	L8	0.280	0.306	0.333	0.344	0.346
	Winter	L8	0.536	0.550	0.574	0.578	0.577
2025	Spring	L9	0.641	0.591	0.558	0.554	0.554
	Summer	L8	0.526	0.549	0.581	0.596	0.600
	Winter	L9	0.348	0.363	0.387	0.393	0.392

Note. SMI = within-scene rescaling of LST; documented for reproducibility. Source: FISHNET Thermal TimeSeries.

Table B.2.7 Mean Albedo by Peri-Urban Class

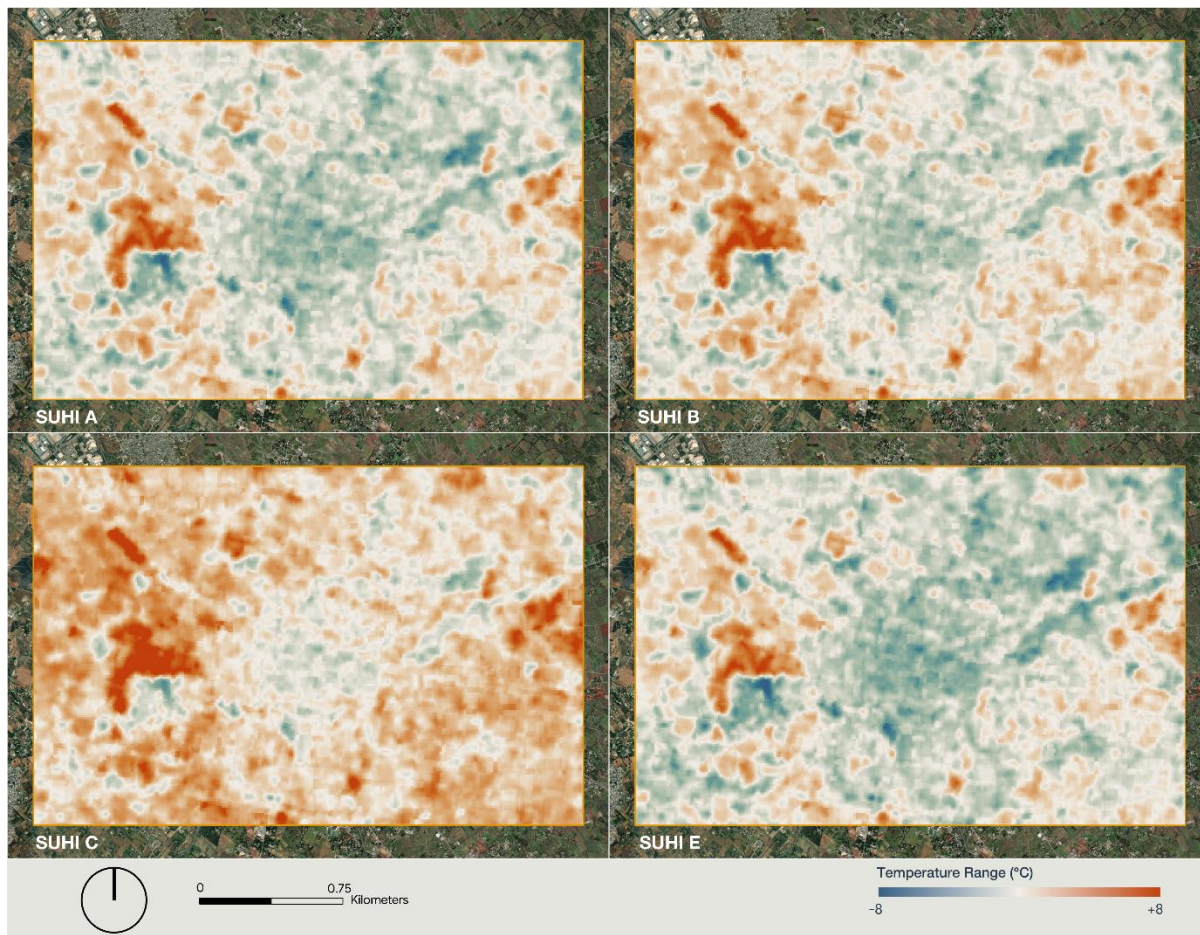
Year	Season	Sensor	Rural Matrix n=1,535	Margin Approach n=2,107	Transition Mosaic n=2,514	Active Margin (★) n=1,763	Critical Fringe (★) n=706
2015	Spring	L8	0.167	0.166	0.166	0.166	0.168
	Summer	L8	0.184	0.182	0.182	0.182	0.184
	Winter	L8	0.148	0.142	0.134	0.133	0.134
2018	Spring	L8	0.169	0.169	0.172	0.174	0.176
	Summer	L8	0.173	0.174	0.178	0.179	0.181
	Winter	L8	0.135	0.132	0.130	0.130	0.132
2021	Spring	L8	0.163	0.166	0.169	0.171	0.174
	Summer	L8	0.181	0.180	0.182	0.181	0.185
	Winter	L8	0.154	0.151	0.149	0.149	0.151
2025	Spring	L9	0.169	0.170	0.172	0.172	0.175
	Summer	L8	0.187	0.184	0.186	0.185	0.188
	Winter	L9	0.136	0.132	0.128	0.127	0.129

Note. Albedo varies little across the gradient at hectare scale, consistent with the §7.7 finding that albedo is not the driver of the ecology thermal ranking. Source: FISHNET Thermal TimeSeries.

B.3 SUHI Variants — Spatial Distributions

Five SUHI variants were computed in Phase 4, each measuring the surface urban heat anomaly against a different baseline. Section §7.4 isolates SUHI_A (anomaly vs. arable + pastures matrix) for the principal seasonal inversion finding. The four-panel figure below demonstrates that the inversion is robust across baseline choice.

Figure B.3 SUHI Variants Map — Summer 2025 (Four-Panel)

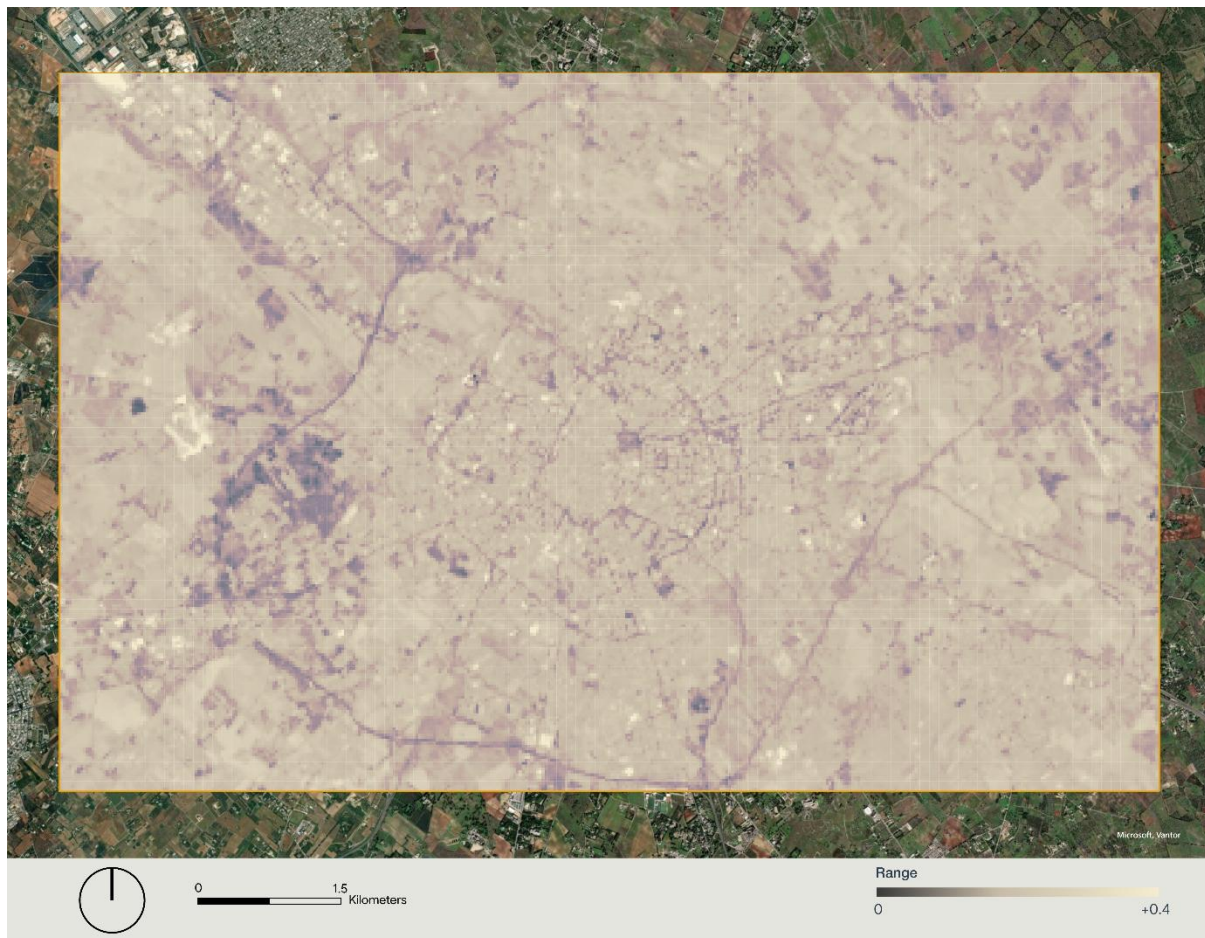


Note. Surface Urban Heat Anomaly variants across the 8,625-cell study area, Summer 2025. Stone karst matrix registers as warmest across all four panels. Source: author's analysis; Landsat 8 Collection-2 Level-2; FISHNET Thermal TimeSeries; EPSG:32634.

B.4 Albedo Spatial Distribution

Section §7.7 identifies moisture-driven evapotranspiration rather than reflectance as the dominant cooling mechanism of the Lecce ecologies. The correlation between summer LST and broadband surface albedo across the grid is functionally negligible at $r = -0.06$, against NDMI's $r = -0.67$ and BSI's $r = +0.59$. This appendix map presents the underlying summer albedo distribution.

Figure B.4 Broadband Surface Albedo — Summer 2025

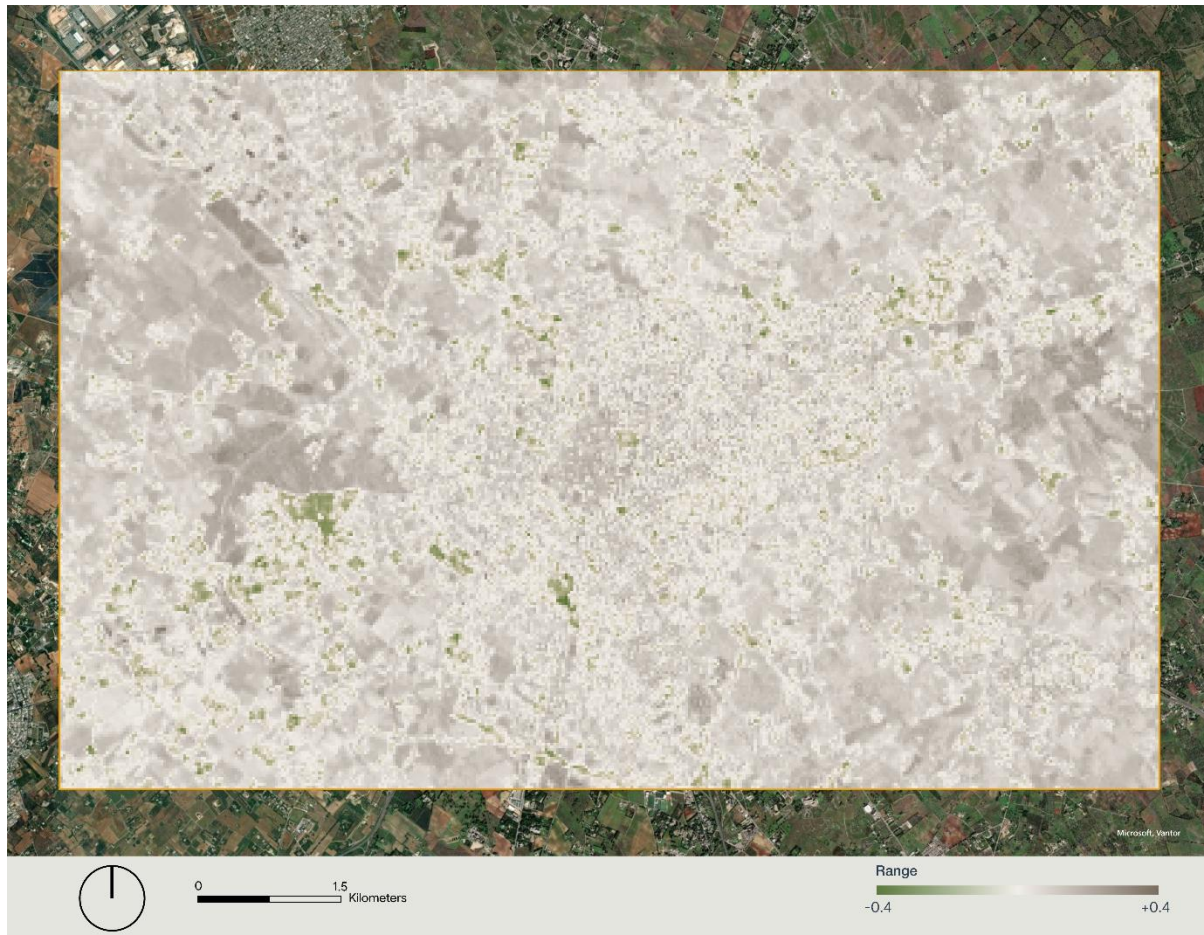


Note. Broadband surface albedo across the study area, Summer 2025. Source: author's analysis; Landsat 8 Collection-2 Level-2 Summer 2025 scene; FISHNET Thermal TimeSeries; EPSG:32634.

B.5 Independent Spectral Witnesses — Single-Scene Maps

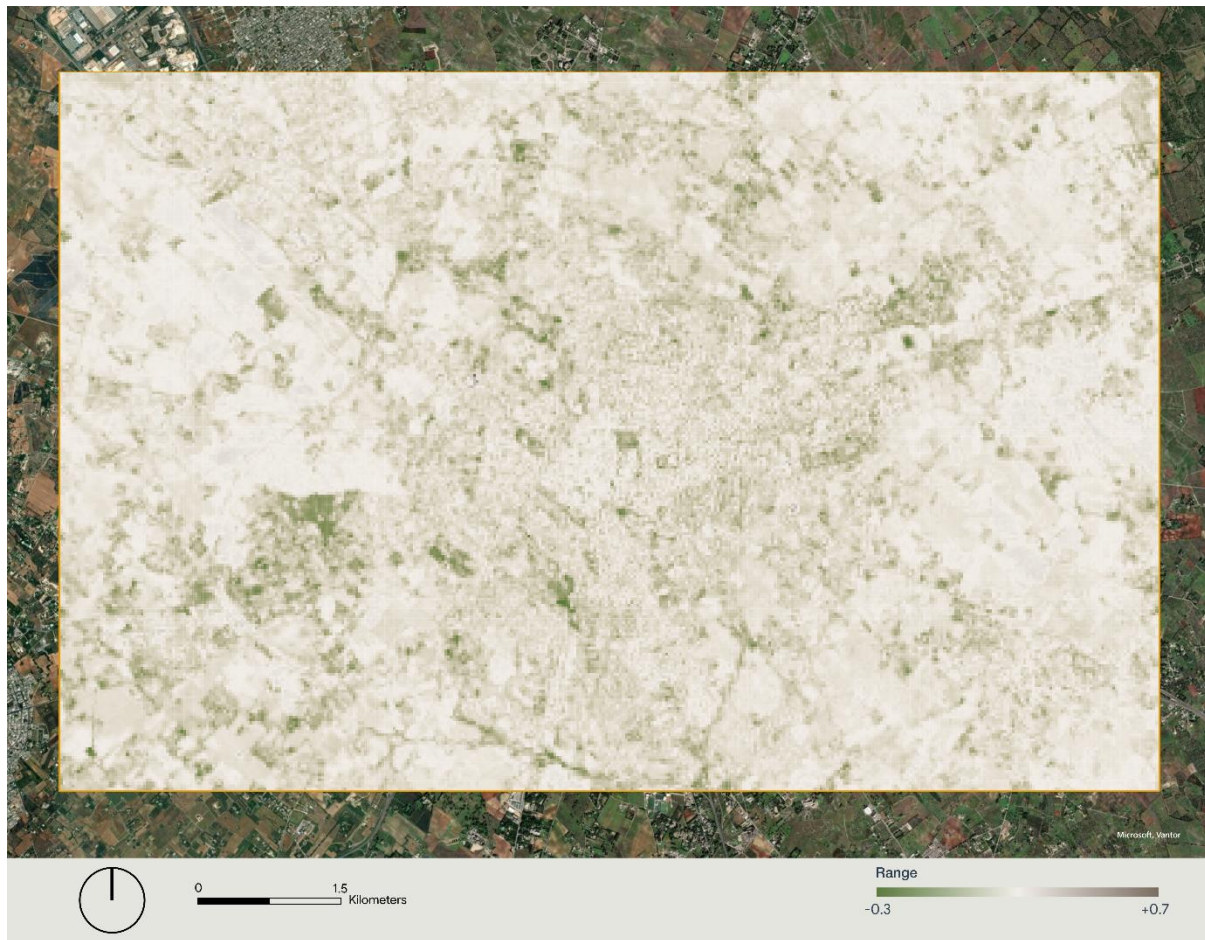
Single-scene grid maps supporting the §7.7 mechanism argument. NDMI and BSI are the strongest independent spectral predictors of summer LST (−0.67 and +0.59 respectively); NDBI is presented as the urban-cover reference.

Figure B.5.1 NDBI - Summer 2025



Note. *Normalized Difference Built-up Index, Summer 2025. $NDBI = (SWIR - NIR) / (SWIR + NIR)$; positive values indicate built-up. Source: FISHNET Thermal TimeSeries; EPSG:32634.*

Figure B.5.2 BSI - Summer 2025



Note. Bare Soil Index, Summer 2025. $BSI = ((SWIR + Red) - (NIR + Blue)) / ((SWIR + Red) + (NIR + Blue))$. Source: FISHNET Thermal TimeSeries; EPSG:32634.

B.6 Sensor Manifest and Data Provenance

All twelve Landsat scenes are Collection-2 Level-2 Science Products (L2SP). Of the twelve, ten are Landsat 8 and two are Landsat 9 (Spring 2025 and Winter 2025). Cross-sensor calibration is documented in the USGS Collection-2 specification as sufficient for combined time-series analysis; an L8-only sub-check of the seasonal inversion finding confirms the pattern holds without L9 contribution.

Table B.6 Landsat Scenes — Acquisition Manifest

Year	Season	Sensor	Acquisition Date	Path / Row	Cloud Cover	QA Status
2015	Spring	Landsat 8	2015-04-16	188/032	<5%	PASS
2015	Summer	Landsat 8	2015-07-21	188/032	<5%	PASS
2015	Winter	Landsat 8	2015-01-10	188/032	<5%	PASS
2018	Spring	Landsat 8	2018-04-24	188/032	<5%	PASS
2018	Summer	Landsat 8	2018-07-13	188/032	<5%	PASS
2018	Winter	Landsat 8	2018-01-18	188/032	<5%	PASS
2021	Spring	Landsat 8	2021-05-02	188/032	<5%	PASS
2021	Summer	Landsat 8	2021-07-21	188/032	<5%	PASS
2021	Winter	Landsat 8	2021-02-27	188/032	<5%	PASS
2025	Spring	Landsat 9	2025-04-19	188/032	<5%	PASS
2025	Summer	Landsat 8	2025-07-16	188/032	<5%	PASS
2025	Winter	Landsat 9	2025-12-15	188/032	<5%	PASS

Note. Path/row 188/032 covers the full nine-municipality study area in a single tile. Fill exact acquisition dates from original scene IDs prior to submission. Source: USGS / EROS Center (2020), Landsat Collection-2 Level-2 Science Products.

APPENDIX C

ArcGIS Pro Model Builder — Automated Extraction Pipeline

Overview. This appendix documents the ArcGIS Pro Model Builder workflow through which the FISHNET Thermal TimeSeries (Fishnet 2) is populated from raw Landsat Collection-2 Level-2 Science Products. The Model Builder architecture represents the reproducibility backbone of the thesis: every thermal and spectral index reported in Chapter 7, and every value populating the tables of Appendix B, is generated through this pipeline rather than through ad-hoc single-scene processing. The pipeline is documented here in three sections. C.1 provides an overview of the pipeline architecture and the rationale for its Model Builder implementation. C.2 presents the sub-model diagrams that execute the per-metric extraction operations. C.3 presents the full-model diagram that orchestrates the sub-models into the complete twelve-scene, multi-metric workflow.

C.1 Overview of the Automated Pipeline

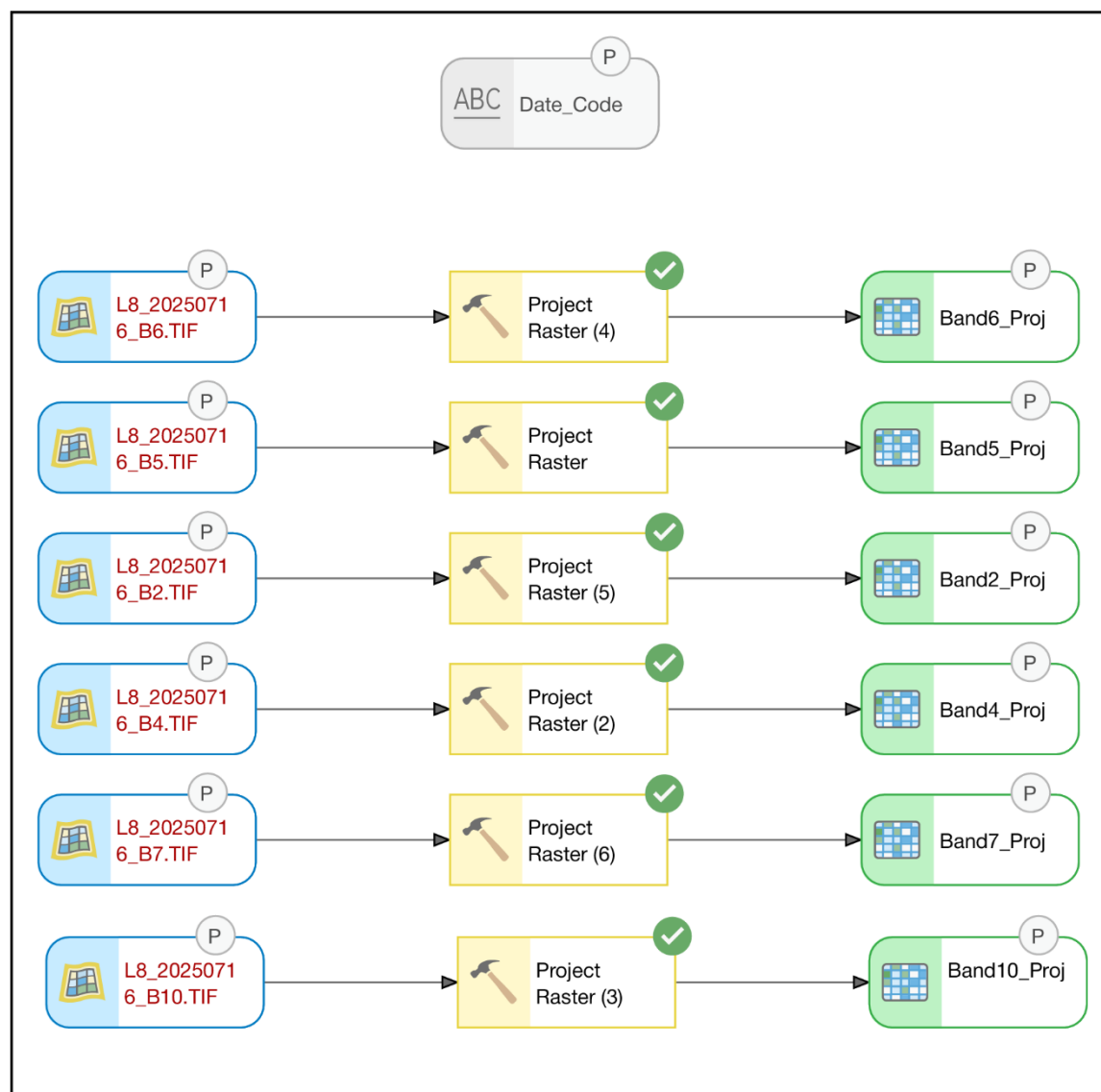
The ArcGIS Pro Model Builder is a visual programming environment that assembles geoprocessing tools into executable workflows through drag-and-drop connections between input datasets, processing operations, and output layers. The visual model, once complete, is functionally equivalent to an arcpy Python script but preserves the analytical logic in a form that is legible to a reader without programming background, an important consideration for a thesis whose primary audience is the urban planning and landscape architecture community rather than the remote-sensing specialist community. The models documented in this appendix were developed and executed in ArcGIS Pro 3.7 on Windows 11, against Lecce Prime Geodatabase (EPSG:32634).

The extraction pipeline is decomposed into a family of sub-models, each responsible for a single class of operation. The rationale for this decomposition is analytical rather than merely technical: each sub-model corresponds to a discrete phase of the RUTZ pipeline as described in Chapter 5, and the visual isolation of each phase into its own model makes the analytical logic of that phase legible independently of the others. A reader can inspect the LST derivation sub-model to understand exactly how surface temperature is derived from Landsat Band 10, without needing to follow the twelve-scene loop that ultimately applies that derivation to every scene in the record.

The Landsat Collection-2 Level-2 Science Products used throughout are documented in Appendix B.6. All spectral bands enter the pipeline as raw Digital Numbers and are rescaled to physical reflectance values using the L2SP scaling factor of 0.0000275 with an offset of -0.2 , following USGS/EROS Center (2020) specification. Band 10 (thermal) is rescaled to Kelvin using the L2SP thermal scaling factor of 0.00341802 with an offset of $+149.0$, then converted to degrees Celsius by subtracting 273.15. All downstream thermal indices such as LST, SUHI variants, UTFVI, SMI, TVDI are therefore expressed in degrees Celsius (LST, SUHI variants) or as dimensionless indices (SMI, TVDI, UTFVI) with no further unit conversion required at the reporting stage.

C.2 Sub-Model Diagrams

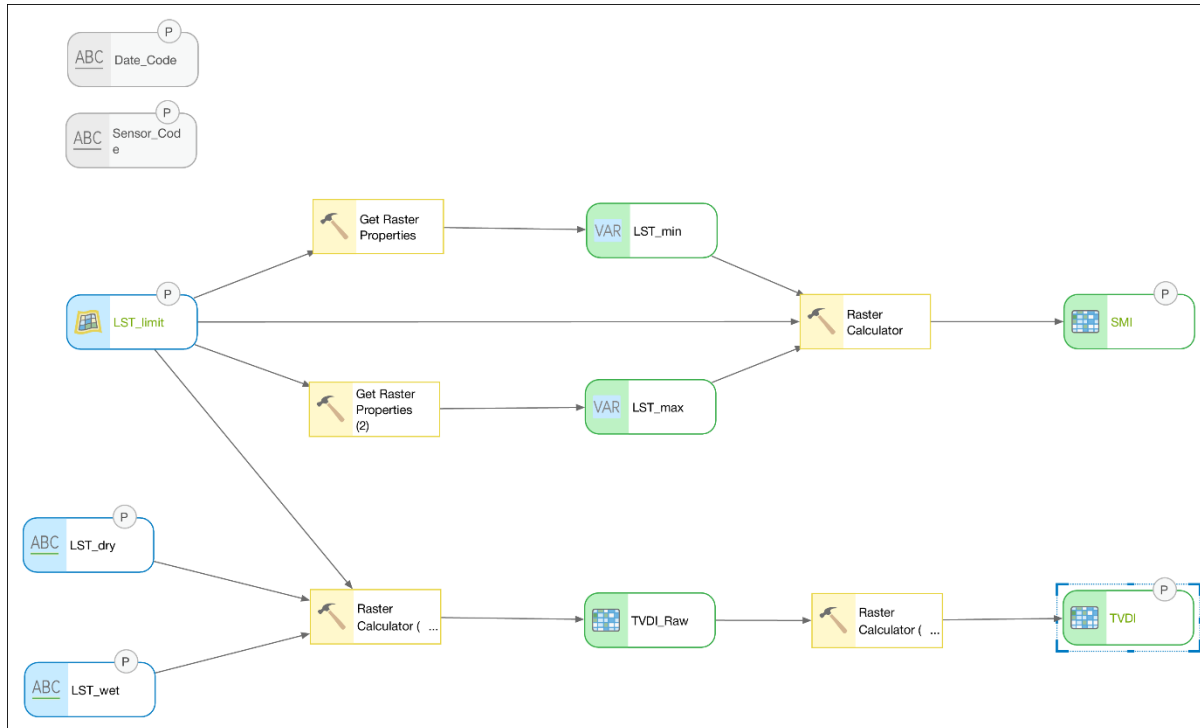
C.2.1 M1 – Preprocessing: Scene Ingestion and Reprojection



Note. M1 ingests the raw Landsat Collection-2 Level-2 Science Product bands for a single acquisition scene — Bands 2 (Blue), 4 (Red), 5 (NIR), 6 (SWIR1), 7 (SWIR2), and 10 (thermal) and reprojects each band to the study area's target coordinate reference system (EPSG:32634, WGS 84 / UTM zone 34N). The Date_Code parameter, threaded through every subsequent sub-model, encodes the acquisition scene identifier so that the same Model Builder execution can be applied across the twelve-scene record without manual reconfiguration. Output: six projected band rasters (Band{n}_Proj) held as intermediate products for consumption by M2 (spectral indices) and M3 (thermal chain). Source: FISHNET Thermal TimeSeries preprocessing GDB.

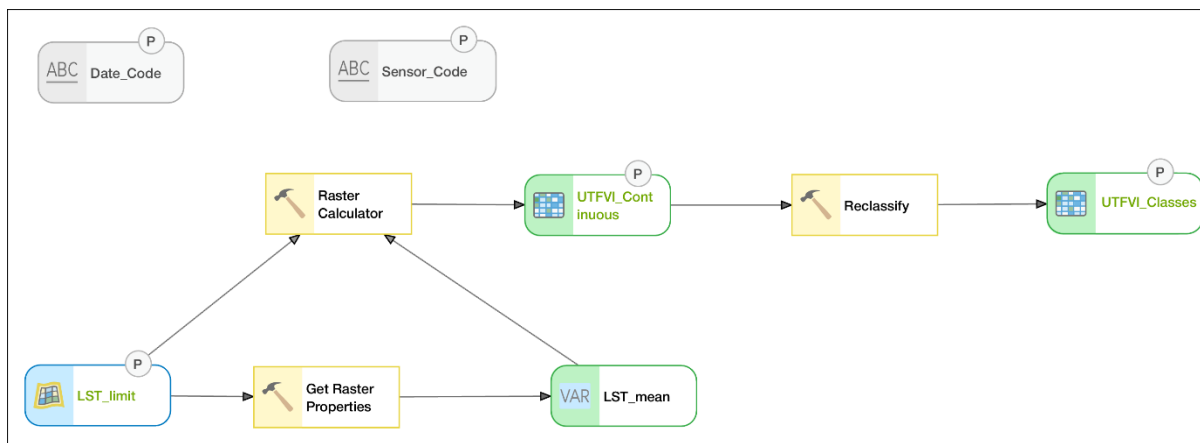
C.2.2 M2 – Spectral Indices: Reflectance-Based Metric Derivation

C.2.4 M4 – Moisture Chain: SMI and TVDI Derivation



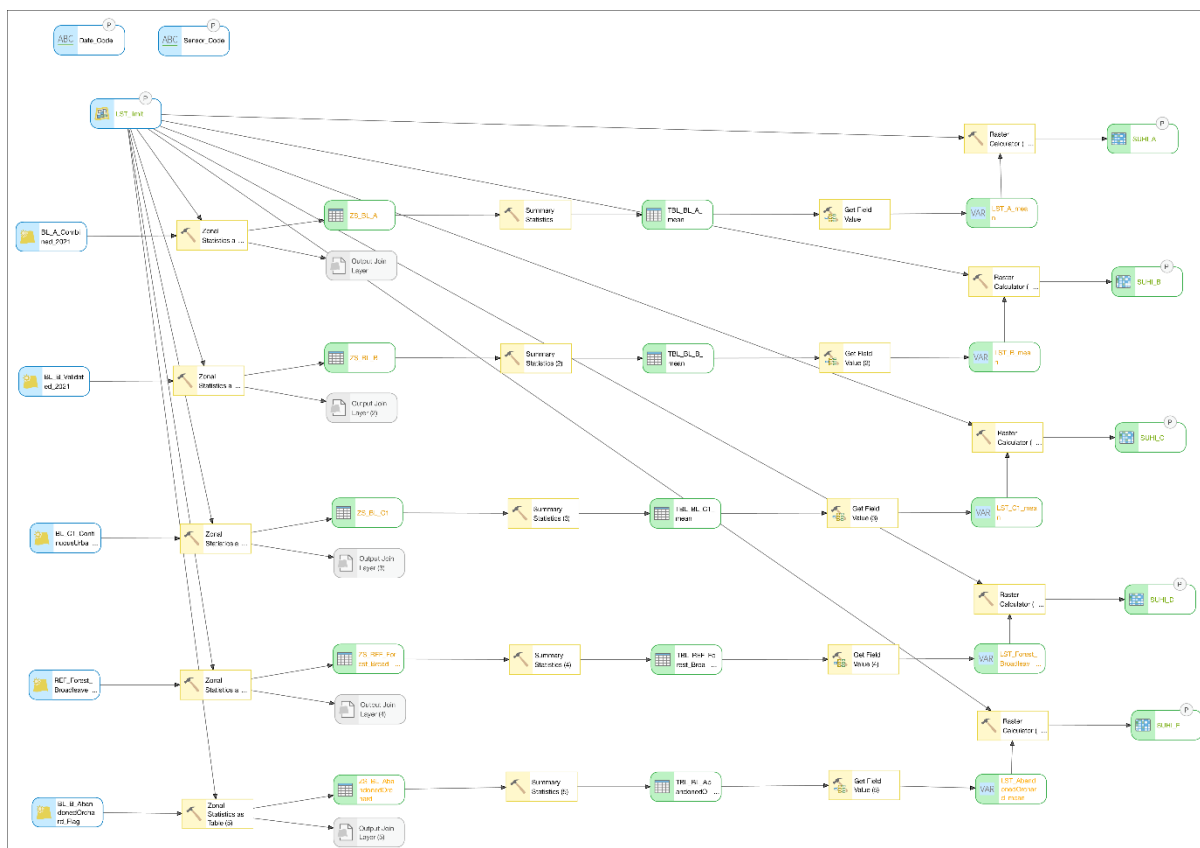
Note. M4 derives the two moisture-diagnostic indices from *LST_limit*: the Soil Moisture Index (SMI) and the Temperature–Vegetation Dryness Index (TVDI). SMI is computed as a within-scene linear rescaling of LST using the *LST_min* and *LST_max* extracted via *Get Raster Properties*. TVDI is computed using the parameterized *LST_dry* and *LST_wet* edge values that Sandholt et al. (2002) define as the temperature limits of the *Ts*/NDVI triangle under maximum-dryness and freely-available-moisture conditions respectively; the *TVDI_Raw* intermediate is then normalized to produce the final TVDI raster. As documented in §5.4 and §7.7 of the main thesis, both SMI and TVDI are within-scene linear rescaling of LST ($r = -1.00$ by construction) and are therefore diagnostic rather than independent moisture witnesses — a methodological caveat preserved by the model's explicit separation of these outputs from the reflectance-band-derived moisture index (NDMI) produced in M2. Output: SMI and TVDI rasters per scene.

C.2.5 M5 – UTFVI: Continuous Index and Six-Class Reclassification



Note. M5 computes the Urban Thermal Field Variance Index per Liu and Zhang (2011): $UTFVI = (LST - LST_mean) / LST_mean$, where LST_mean is extracted from the LST_limit raster via Get Raster Properties. The Raster Calculator produces the continuous UTFVI raster ($UTFVI_Continuous$), which is then passed to the Reclassify tool to generate the six-class categorical output ($UTFVI_Classes$) using the Liu and Zhang threshold system: Excellent (< 0), Good ($0-0.005$), Normal ($0.005-0.010$), Bad ($0.010-0.015$), Worse ($0.015-0.020$), Worst (> 0.020). This classified output is the source of the `MAJORITY_UTFVI_C_MAJ_{scene}` fields reported in Chapter 7 and populates the categorical thermal-stress column of the FISHNET Thermal TimeSeries. Output: UTFVI (continuous) and UTFVI_Classes (five-class categorical).

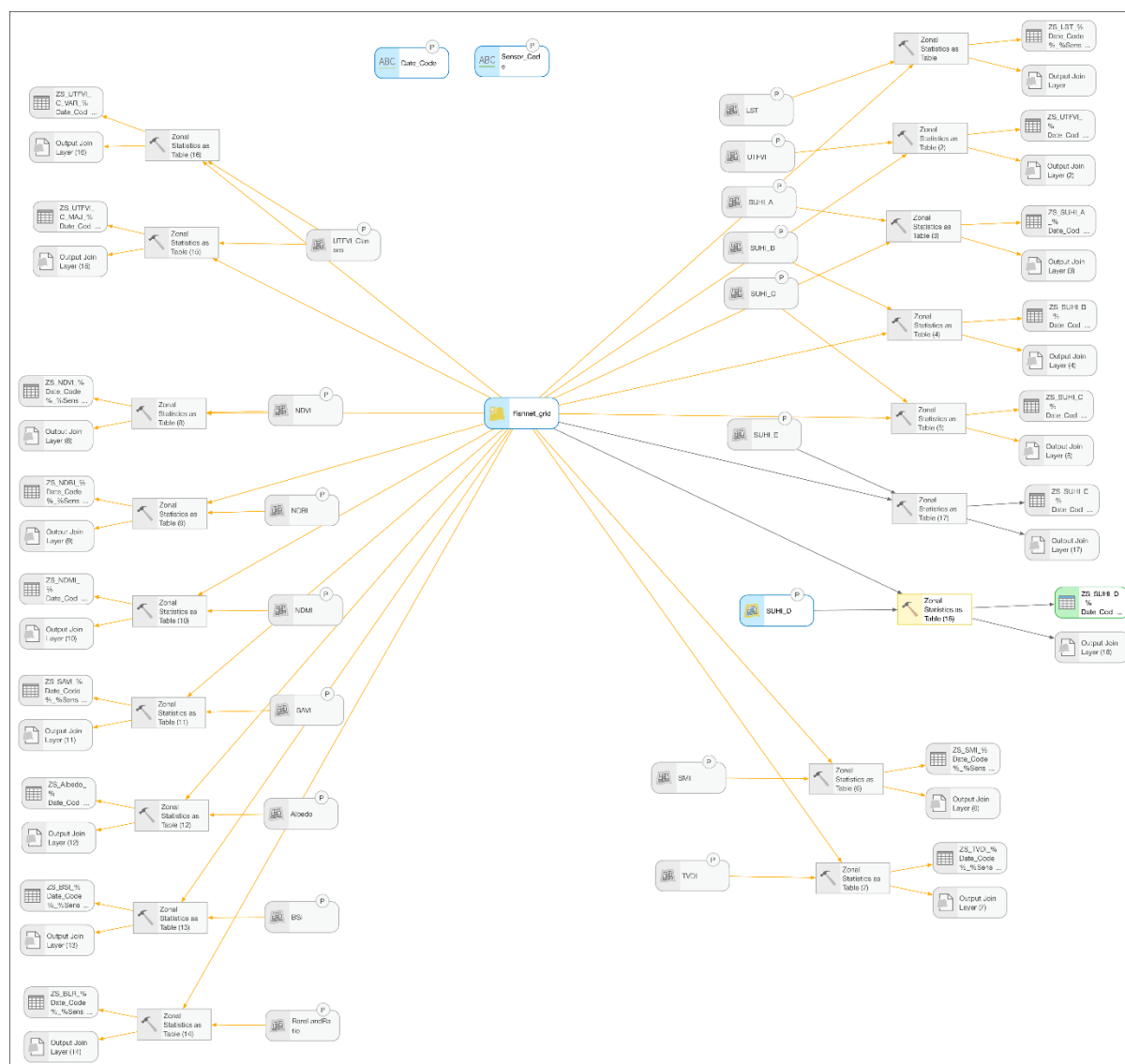
C.2.6 M6 – SUHI Variants: Five Baseline Anomalies



Note. M6 computes the five Surface Urban Heat Island variants defined in Chapter 5, each measuring the surface anomaly of LST_limit against a different reference baseline: $SUHI_A$ against Baseline A (combined arable + pastures matrix, $BL_A_Combined_2021$), $SUHI_B$ against Baseline B (validated permanent crops, $BL_B_Validated_2021$), $SUHI_C$ against the merged urban fabric of the three Lithic Core density tiers ($BL_C1_ContinuousUrban$), $SUHI_D$ against the broadleaved forest reference ($REF_Forest_Broadleaved$, the maximum cooling ceiling), and $SUHI_E$ against the abandoned-orchard flag layer ($BL_B_AbandonedOrchard_Flag$, the acute vulnerability floor). For each baseline, the workflow executes

Zonal Statistics as Table on the LST raster masked by the baseline polygon, extracts the mean LST via Summary Statistics and Get Field Value, and passes that mean as a scalar variable (LST_A_mean, LST_B_mean, LST_C1_mean, LST_Forest_Broadleaved_mean, LST_AbandonedOrchard_mean) into the Raster Calculator to compute the cell-wise anomaly. Section §7.4 isolates SUHI_A for the principal seasonal-inversion finding; the remaining variants are documented in Appendix B.3 and confirm the inversion is robust to baseline choice. Output: five SUHI variant rasters per scene.

C.2.7 M7 — Data Extraction: Zonal Statistics to Fishnet

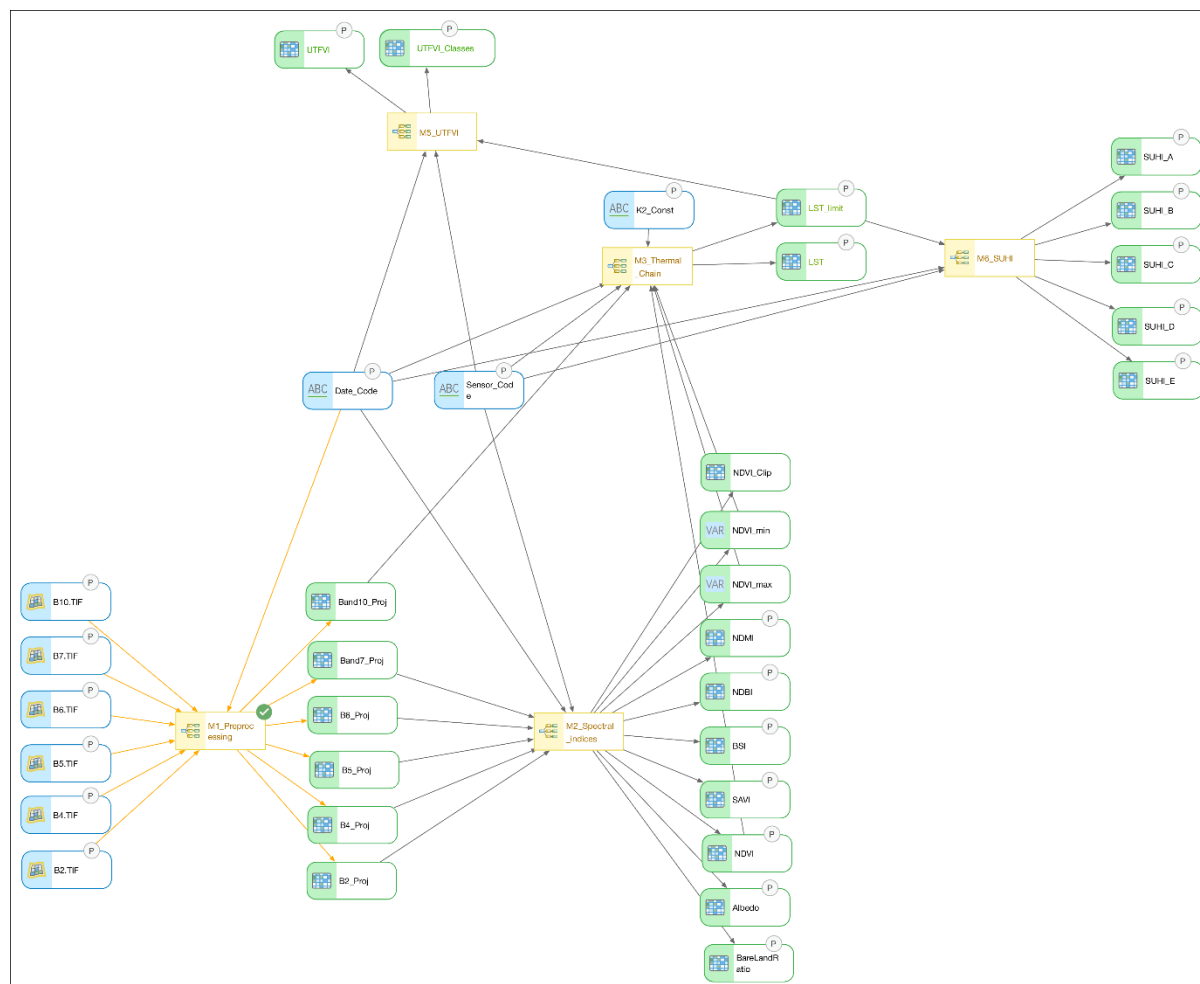


Note. M7 executes the aggregation that translates the M2–M6 raster outputs to the 100-metre fishnet cell. Fifteen input rasters (LST, UTFVI continuous, UTFVI classified, SUHI_A through SUHI_E, NDVI, NDBI, NDMI, SAVI, Albedo, BSI, BareLandRatio, SMI, TVDI) are each passed to Zonal Statistics as Table against the Fishnet_grid polygon layer, producing 18 output tables (ZS_{metric}_{Date_Code}_{Sensor_Code}) that are subsequently joined to FISHNET Master Profile on OBJECTID. The dynamic %Date_Code% and %Sensor_Code% tokens ensure that every scene's output tables carry unique names, enabling the twelve-scene record to be assembled in the FISHNET Thermal TimeSeries without collision. Every field appearing in Appendix B's populated tables and therefore every value underlying the empirical findings of Chapters 7, 9, and 10 is produced by this sub-model. Output: eighteen ZS tables per scene, joined to the master fishnet.

C.3 Full-Model Diagram

The full-model diagram orchestrates the five sub-models above into the complete twelve-scene, multi-metric workflow that populates the FISHNET Thermal TimeSeries dataset. The full model is presented here as a single visual document, its scale calibrated to make the pipeline architecture legible at a page-sized rendering while preserving readability of the individual node labels.

Figure C.1 ArcGIS Pro Model Builder: Full Extraction Pipeline



Note. The Master Model orchestrates the seven sub-models (M1–M7) documented in Appendix C.2 into the complete twelve-scene, multi-metric workflow that populates the FISHNET Thermal TimeSeries fishnet. The *Date_Code* and *Sensor_Code* parameters (top of canvas) propagate the acquisition scene identifier and the sensor family (L8 or L9) through every sub-model, ensuring that the K2 thermal constant in M3, the L2SP scaling factors in M1, and the output table naming in M7 all adapt automatically to the scene being processed. The *K2_Const* variable resolves the sensor-specific brightness-temperature constant. The pipeline delivers five categories of output: the continuous LST raster and its *Grid_limit*-clipped variant (from M3); the seven spectral index rasters from M2; the two moisture-diagnostic rasters SMI and TVDI (from M4); the continuous UTFVI raster and its six-class categorical reclassification (from M5); and the five SUHI variant rasters, one per baseline reference surface (from M6). All outputs are then aggregated to the 100-metre fishnet in M7 (not shown in the Master Model diagram; documented separately in Appendix C.2.7) and joined to FISHNET Master Profile on OBJECTID. The Master Model is preserved in *Lecce_Prime.gdb\ModelBuilder\FishnetTimeSeries_MasterPipeline.model* for reproducibility. Source: author's Model Builder implementation.

The full-model diagram is the operative reproducibility contribution of the thesis: any subsequent researcher with access to the same Landsat scenes, the same Copernicus reference layers, and this appendix's model documentation can regenerate the FISHNET Thermal TimeSeries fishnet from scratch, obtaining values within floating-point precision of those reported in Chapters 6–10. The pipeline is not a black box. It is a documented instrument, and its documentation is the ground on which every empirical claim in Part III of this thesis rests.